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U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 130.

B. T. GALLOWAY, *Chief of Bureau.*

DRY-LAND AGRICULTURE.

PAPERS READ AT THE SECOND ANNUAL MEETING OF THE COOPERATIVE EXPERIMENT ASSOCIATION OF THE GREAT PLAINS AREA, HELD AT MANHATTAN, KANS., JUNE 26-27, 1907.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., June 8, 1908.

Sir: I have the honor to transmit herewith some papers on dry-land agriculture read at the second annual meeting of the Cooperative Experiment Association of the Great Plains Area, and to recommend their publication as a bulletin of the series of this Bureau.

The association mentioned is an organization made up of workers in the Department of Agriculture and in the State agricultural experiment stations who are cooperating in the agricultural development of the Great Plains. This organization has proved of great value in coordinating the various lines of work being conducted in the Great Plains and in bringing the men into closer and more sympathetic association. It is believed that the papers read at its meetings will prove of value to all interested in the agricultural development of this region. The membership of the association is confined entirely to Department and experiment station men, most of whom are either officials or collaborators of the Department of Agriculture.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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DRY-LAND AGRICULTURE.

PAPERS READ AT THE SECOND ANNUAL MEETING OF THE COOPERATIVE EXPERIMENT ASSOCIATION OF THE GREAT PLAINS AREA, HELD AT MANHATTAN, KANS., JUNE 26 AND 27, 1907.

INTRODUCTORY STATEMENT.

While establishing the work in dry-land agriculture in the Great Plains area the need was recognized of bringing the widely-scattered station workers in the area together for the purpose of discussing and conferring with each other about the various lines of cooperative work to be carried on at these stations. A meeting was held in Washington, D. C., on November 15, 1905, for the purpose of considering the advisability of organizing an association which would bring into close relationship the officers of the Department of Agriculture and of the experiment stations who were carrying on cooperative work in dry-land agriculture in the Great Plains area.

The meeting was presided over by Dr. B. T. Galloway, Chief of the Bureau of Plant Industry, and there were present either the presidents of the agricultural colleges or the directors of the agricultural experiment stations of the States lying within the area, as well as a number of Department men interested in the work.

An organization was effected and the title of "The Cooperative Experiment Association of the Great Plains Area" was adopted. The purpose of this organization, it was stated, "shall be to encourage and facilitate the coordination, systematization, and unification of all cooperative experimental work to be engaged in by the Bureau of Plant Industry and the experiment stations and substations of the several States included in whole or in part within the Great Plains area."

It was decided that meetings should be held at least twice each year—one of these to be held within the area—at which "papers shall be read, addresses delivered, and discussions carried on bearing directly upon the cooperative work of the Great Plains area." It was agreed that the directors and agriculturists of all States included in whole or in part within the Great Plains area and other members of the experiment stations' staffs engaged in cooperation with the Department of Agriculture and all officers and members of the Bureau of Plant Industry who are interested and actively engaged in cooperative work in this area should be considered eligible for membership. Officers are to be elected annually.

The first annual meeting was held at Lincoln, Nebr., June 21–22, 1906, at which meeting a number of very interesting papers on important problems were read, but, owing to the fact that no arrangements had yet been made for the publication of papers by the association, they were published elsewhere.

The second annual meeting was held at Manhattan, Kans., June 26–27, 1907, with President E. A. Burnett in the chair. After an address of welcome by President E. R. Nicholls, of the Kansas Agricultural College, several papers were read and discussed. All are included in this bulletin, except one by Mr. T. H. Kearney, of the Department of Agriculture, upon "A striking example of dry-land arboriculture," describing the growing of the date palm in the Sahara; a paper by Prof. J. B. Nelson, superintendent of dry-farm work, Montana, upon "Dry farming in Montana;" and a paper by Dr. R. P. Hibbard, of the Department of Agriculture, upon "Soil bacteria."

E. C. Chilcott,
Agriculturist in Charge of Dry-Land
Agriculture Investigations.

Washington, D. C., *May 26, 1908.*

THE DEVELOPMENT OF DRY-LAND FARMING.

By E. A. Burnett, *Director of the Nebraska Agricultural Experiment Station, Lincoln, Nebr.*

The development of agriculture in the semiarid regions of the Great Plains area is a question of national importance. It involves the settlement of a large area of fertile land, awaiting only the conservation of moisture sufficient to insure the growth of crops or the selection of varieties which can maintain themselves under conditions which are often favorable, but sometimes extremely unfavorable, to crop production. The conservation of moisture in the soil by tillage to make up for the lack of rainfall during the growing period, the selection of early-maturing and of drought-resistant crops, and the practice of crop rotation to maintain fertility and the proper physical conditions of the soil seem to me the great problems which must be worked out in order that crop production may be extended into the region which has hitherto been occupied largely for grazing purposes.

Moisture is the great problem. Much of this area receives sufficient rainfall each year to grow an abundant crop, provided all this water could be trapped where it falls and be used by the crop. The great problem is to trap the water, to absorb the rain as it falls and prevent its running off, to impound the water in the subsoil reservoir and reserve it for the use of the crop when it may be needed for the purpose.

In this region of scant rainfall the distribution of water is particularly uncertain, a large proportion of the precipitation falling as local showers, which may come at opportune times over a small area, but leave many sections of the country—in fact, the greater part—to depend for the success of the crop upon water which has fallen at some earlier date. Unless it is possible through the conservation of moisture in the soil to grow certain grain crops practically without precipitation during a period of their growth, grain production in this region will necessarily be uncertain and hazardous. Not only is the precipitation uncertain in this region, but it often falls greatly in excess of the amount needed for immediate use, in the form of violent local storms which are so clean-cut in their outline that one farm may receive an excess of water while the adjoining land is left dry and thirsting for rain. Grass land where closely pastured loses much of the rainfall by run-off and evaporation. Land which is plowed and cultivated to keep the surface loose furnishes ideal conditions for the absorption of rain and also furnishes the best condition to prevent the escape of the water which has entered the soil.

It is unnecessary for me to discuss the method of conservation of soil moisture before this body. We recognize the fact that soil moisture can be stored by cultivation sufficiently to insure a crop the following year where crop production would be hazardous or impossible without this previous preparation. The extent to which moisture can be stored, the extent and kind of cultivation necessary, and the minimum rainfall under which crop production is possible, I leave for others to discuss. These questions still need more accurate and extensive investigation. Many thousand acres of land which will not grow a crop every year are now being farmed by this method. Where rainfall is nearly sufficient to produce a crop the summer fallow is not needed every alternate year. Possibly only a short period of tillage previous to the sowing of the crop is necessary, but it is essential that an abundance of moisture should be present, especially in the subsoil. We must not be deceived into the idea that it will always rain just at the right time. This is exactly the thing which does not happen. Enough water should be stored in the soil to make the crop sure. If rainfall is abundant you will still produce a crop. I believe the conservation of soil moisture to be the most important question in farming in the semiarid country.

Summer tillage does more than to store moisture. It encourages the accumulation of nitrates in the soil. It puts the land in the proper physical condition for the growth of the crop, so that at the time the crop is planted all the conditions are favorable for its immediate germination and growth.

The problem of preventing the blowing of the soil under this intensive method of cultivation is serious. The high evaporation of moisture from the soil in the western country is due largely to the high velocity of the wind. The cultivation necessary to store moisture and produce the perfect tilth required for the best growth of the crop favors both the blowing and washing of soils. Rolling lands can not long be cultivated under such methods without washing badly, and I know of no alternative but to seed these lands down to grass or keep them for a considerable portion of the time in sod. Fortunately, over most of this region alfalfa can be grown with considerable success—over much of it with very marked success—and, if it is possible to cultivate land in a rotation by which it shall be held in grass for three or four years in a seven or eight year rotation, much of the damage which would otherwise result from excessive washing and blowing can probably be overcome.

The selection of the soil will also help materially in preventing its loss by blowing. We have not yet reached the period when all the land in this western area must be cultivated. In fact, it is probable that only a small percentage of this land should be under plow, and that only gradually should we try to reclaim for the use of the grain farmer the country which has proven successful as cattle range. The hard, level lands may be used for cultivation, while the rougher and sandier portions of the country can be maintained as range. In this way we shall minimize or overcome the losses from blowing and soil washing.

The planting of trees, especially for wind-breaks, should not go without mention in this connection, as nothing will so permanently check the force of the wind as the growth of timber; but the production of forests requires a generation. The influence of wind-breaks on the velocity of the wind is but local, affecting the land for only a short distance away from the wind-break. Agriculture on a large scale must depend upon some other method of preventing the loss of soil than by foresting this great area of land which we seek to put under the plow.

The selection of varieties of crops suited to the dry region is also of prime importance in connection with this question. Certain principles should be worked out which apply to the general crops to be grown in this region. In this connection two important factors should be considered: (1) The selection of crops which can be grown and matured before the period of ordinary summer drought, and (2) the selection of those crops which can withstand a period of drought and continue their growth when sufficient moisture is later available.

In this connection it occurs to me that throughout a large portion of the Great Plains area winter wheat should be looked upon as a standard crop, and an effort should be made to determine the limits under which it may be successfully grown. It is true that the time when drought conditions will prevail can not be determined to a certainty. Winter drought is a common form. While spring rains are generally abundant, they are sometimes lacking until late spring or early summer. On the whole, however, I believe that winter wheat may be grown with little danger of winterkilling or of early spring drought if sufficient attention is given to tillage and the conservation of moisture previous to sowing the crop. Winter wheat possesses a decided advantage over the spring varieties—even over the durum wheats—which have been grown in Nebraska. It ripens considerably earlier and outyields the spring varieties. It is not greatly injured by early spring droughts when sown upon summer-tilled land. Under the conditions prevailing in Nebraska it has been possible to secure a good stand of winter wheat in the fall when lands not under summer tillage were too dry to germinate grain. In this connection it may be interesting to state that light seeding—from one-half bushel to one bushel per acre—has yielded as well as heavier seedings. There seems to be little difference in the thickness of the grain at the ripening time between plats which had received one-half bushel of seed per acre and those which had received one bushel or more. This would indicate that in the ordinary heavy seeding only a portion of the grain ever occupies the ground, and that thick seeding at most does nothing more than prevent the tillering of the grain. It is presupposed in cases where light seeding is followed that the weeds have been killed so that they will not come on and occupy the ground before the grain has developed sufficiently to prevent their growth. The yields of winter wheat at the substation at North Platte in the year 1906 were as follows:

Turkish Red wheat, sown at the rate of 1¼ bushels per acre, yielded 42.13 bushels.

Turkish Red wheat, sown at the rate of 1 bushel per acre, yielded 44 bushels.

Turkish Red wheat, sown at the rate of ½ bushel per acre, yielded 42.3 bushels.

Kharkof wheat, sown at the rate of 1¼ bushels per acre, yielded 45.7 bushels.

The crop of winter wheat for 1907 at the North Platte substation promises to be as good as that harvested the previous year.

The durum wheats are now commonly grown throughout western Nebraska, and with quite satisfactory results. The area is annually extending into regions where wheat has not before been produced as a profitable crop. I am still of the opinion, however, that winter wheat will be more profitable than the durum wheat under the best methods of tillage, and that by this process the line of winter-wheat production can be pushed far into the dry country.

In the local tests of oats at the Nebraska substation, the early-ripening varieties have uniformly produced the largest and most satisfactory yields, later varieties being injured by drought and rust. Among these early and successful varieties may be mentioned the Kherson, the Sixty-Day, and the Texas Red.

Our ordinary local barley has proved superior to any of the introduced varieties and furnishes a large quantity of grain for local consumption.

While corn is a somewhat uncertain crop in the dry region, it is also one of the most adaptable to local conditions, and there is no question about the ability of the station worker to develop varieties of corn which will be suited to the localities in which they are grown. The question as to what extent the corn crop may prepare the land for a subsequent small-grain crop should be carefully studied. I am uncertain as to the degree of drought resistance which can be produced in the corn plant, but cultivation will largely overcome the effect of drought by accumulating moisture in the soil for the use of the plant during the latter part of its growing period.

It is probable that the Kafir corns will always be more drought-resistant than the Indian corn and that they will be used for grain production in the southern portion of the Great Plains area.

I shall hope to hear a discussion during this meeting of what can be accomplished in securing crops which can actually grow and mature with a smaller quantity of water than those crops now being grown in the humid regions. If it can be demonstrated that properly selected crops can grow and mature with certainty in the dry region, producing a ton of dry matter, either grain or forage, with smaller amounts of water than our ordinary crops, this will be one of the most successful methods of pushing settlement into the semi-arid region. The durum wheats, Kafir corn, and sorghum give some promise along this line. I believe, however, it should be the work of the members of this association to determine whether these so-called drought-resistant crops actually grow and mature with less water, or whether they simply have a greater power of endurance under drought conditions, enabling them to withstand somewhat longer or more severe conditions of drought than tenderer varieties of crops.

The river valleys of this area are noted for their production of alfalfa, perhaps the most wonderful forage crop of the region. Either with or without irrigation they furnish a very large amount of forage for the winter maintenance and the fattening of cattle and sheep. Alfalfa has already extended itself in a limited way to the drier lands of this region and has demonstrated its ability to grow under dry conditions when once thoroughly established. This association should endeavor to determine the most extreme conditions under which alfalfa can be profitably grown on the high table-lands of the region, as I believe it easily possible to extend the area under alfalfa in a way which shall very greatly increase the stock-carrying capacity of the country. The successful introduction of alfalfa removes the last difficulty in the production of pork and the development of the dairy industry, two extremely profitable lines of farming which have not been much developed in this region. Alfalfa seed production also promises to be an industry which can be made highly profitable on the cheap unirrigated lands where the rainfall reaches from 10 to 20 inches per annum.

The region under consideration has developed into a great stock-growing country. The conditions of past years have very largely driven the grain grower out and allowed the cattleman and sheep-man to remain. The stockman has remained because he has been able to adapt his industry to the natural conditions of the country. He has gathered what nature has produced. He has not, as a rule, expended money upon the growing of cultivated crops. His industry has been reasonably sure, but it has produced only a small revenue per acre and has not been conducive to the general settlement of the country.

Still, the fact that the grain grower has been driven from the land by adverse conditions, often more than once from the same region, is an indication to us that the settlement of the semiarid region with farmers who depend upon grain production should be well considered. Experiment stations should not be used to exploit the country and to bring into these regions men who can not or will not practice successful methods of grain growing. Intensive methods of tillage require a large expenditure for farm machinery and motive power in order to cultivate a small area of land. The average settler has not the means with which to secure this equipment; neither has he the knowledge which will enable him to put it into successful operation. The settlement of this region will progress much more rapidly and more satisfactorily if the settlers already in the country can be induced to practice somewhat better methods and to determine the success of new varieties and of new methods under farm conditions before an attempt is made to bring settlers into the country whose success is dependent upon conditions which they can not meet.

It is a mistake to assume that the climate of this region is changing permanently—that the rainfall follows the plow. While it is true that the conservation of moisture leaves more available for the crop, we have had wet years and dry years, lean years and fat years, in this region since the records of its settlement are available. The cattleman profits less by the years of abundant rainfall than the man who is growing grain. He also suffers less during the periods of drought. Having invested little in labor, seed, and farm machinery, he risks little in times of adverse conditions. His grass cures upon the ground, and he winters his cattle upon the range with limited amounts of forage which he has stored for their protection during adverse weather conditions.

But people are not content to let the cattleman occupy this region unmolested. The pressure for settlement from outside regions is continuous. The high-priced lands of the rich arable country are driving the poor man to the region of cheaper lands. It is the province of the stations in this region to determine how this settler who has already occupied the land may succeed, how he may protect himself so as not to be driven out when adverse years come upon the country, and how he may help to develop this country into one which will support a larger population and give a more certain revenue to its people. The high-priced land of older sections has increased the price of land in the Great Plains area. The cattleman can no longer expect to hold 20 or 25 acres of land for a steer. It must be grown on a much smaller area. This means that the question of forage and possibly of grains for the steer's maintenance must be studied by the cattleman himself or he will be driven from the country by the small farmer and rancher who will give more personal attention to his cattle, producing a small area of crops, but never forgetting that grass is the crop which has built up and developed the region.

The better land will be cultivated first. Probably not over 10 or 20 per cent of the land between the ninety-ninth and one hundred and fourth meridian should be under the plow. If grasses can be produced which will support more live stock than heretofore, these should gradually be introduced. Forage crops should be grown in as large areas as possible for use in wintering the live stock which is now in the country. The losses of the ranchman from the depletion of his herd in winter through starvation must be overcome. Good business sense does not permit that a man with 100 head of cattle, weighing 100,000 pounds in the fall, should permit these cattle to come through the winter with a loss of 15,000 pounds of flesh which he must regain by months of summer growth. If the steer must live off a smaller area of land it means he must reach a market weight at an earlier age. This means better feed, more continuous growth, and the use of forage instead of the open range in winter.

The experiment station worker can aid in this matter by determining the methods which will make crop production successful in this area, by determining the varieties of crops which can be produced with greatest certainty and at largest commercial profit, and by suggesting the evolution which must take place in the present farm methods in order that the settler may prosper and that homes may be built in the country upon a substantial basis.

SOME SOIL STUDIES IN DRY-LAND REGIONS.

By F. J. Alway, *Chemist, Nebraska Agricultural Experiment Station, Lincoln, Nebr.*

The soils and crops of which I shall speak to-day are those of the hard spring-wheat region of Saskatchewan, particularly those of the experimental farm at Indian Head and of the region westward to Moose Jaw, a district that has been settled, though rather sparsely, for some twenty years. I wish to speak of the conditions and crops in this district somewhat in detail, because it is, in so far as I am aware, the only part of the Great Plains area in which the so-called "dry farming" has been tried for a considerable length of time and in which it has been found to be an economic success. It is a mistake to imagine that the Great Plains region suddenly ends at the forty-ninth parallel. Strange as it may seem, this new country is able to furnish valuable data bearing on the subject that we have met to discuss. Indian Head has the only experimental farm in the Great Plains area whose records go back before the dry years of the nineties. While this northern farm may have advantages of temperature and possibly of soil not enjoyed by the greater portion of the Great Plains region, these advantages must be inconsiderable when compared with those of parts of North Dakota, and may be slight even when compared with parts of western Kansas and western Nebraska.

Before my first visit to Saskatchewan I had visited western Nebraska and western Kansas looking for evidences of successful "dry farming," and was, accordingly, somewhat familiar with the conditions of soil and vegetation of the central portion of the Great Plains area.

The extreme northern part of the Great Plains region is similar in appearance and vegetation to the prairies and plains of Nebraska and Kansas.

Very little study has been devoted to the chemical and physical properties of the soils of the northern portion of the Great Plains region, better known as the Canadian Northwest. In the few investigations that have been conducted there methods have been employed which are adapted to the humid climate of eastern Canada, but which are ill-suited to the conditions that have produced the prairies and plains..

The commonly accepted explanation of the large yields of small grains obtained in Saskatchewan is quite erroneous and has served to prevent the recognition of the value to the agricultural interests of the semiarid portions of the United States of the large amount of data contained in the annual reports of the Indian Head experimental farm, covering a period of almost twenty years. The climate of the portion of the Saskatchewan with which I will deal is distinguished from that of the prairie portions of the United States chiefly by its lower winter temperature, its slightly longer summer days, and its low precipitation, the rainfall occasionally amounting to less than 5 inches during the crop season. Both American and English authorities have advanced or accepted in explanation of the large yields of grain in that region the theory that the frost penetrates to a great depth during the winter and that during the summer months this furnishes a constant supply of moisture to the growing grain. This theory seems to be due to a confusion of the two meanings of the term "frost," as though the cold which entered the soil in the winter time changed there to frozen water. Sir William Crookes in his presidential address before the British Association for the Advancement of Science in 1908 chose as his subject "The wheat problem." In the course of his address he made the following statement:

> The fertility of the Northwest Provinces of the Dominion of Canada is due to an exceptional and curious circumstance. In winter the ground freezes to a considerable depth. Wheat is sown in the spring, generally April, when the frozen ground has become thawed to a depth of 3 inches. Under the hot sun of the short summer the grain sprouts with surprising rapidity, partly because the grains are supplied with water from the thawing depths. The summer is too short to thaw the ground thoroughly, and gate posts and other dead wood extracted in the autumn are found still frozen at their lower ends.

Sir William had passed through Saskatchewan the preceding summer. Storer, in his text book on agriculture, as an illustration of how melting ice may serve as a useful store of moisture in certain situations and for certain crops, makes the following statement regarding Assiniboia, which is now southern Saskatchewan:

> Even in late July some of the soil still holds the winter's frost at a depth of several feet below the surface. This underground layer of frozen earth is believed to explain the wonderful fertility of the soil, as the frost in gradually coming to the surface during the summer months creates a moisture which, meeting the warmth from above, forms a kind of natural hotbed. This moisture counteracts the scarcity of rain during the spring and summer and accounts for the grain being forced with such amazing rapidity after the late sowing.

Up to the present time this "frost" explanation seems to have passed without criticism.

I am convinced that the soil of the prairie and of the grain fields of Saskatchewan does not remain frozen throughout the summer at any depth. The winter of 1903–4 was the coldest that had occurred in twelve years. The winter had been unusually severe, the spring was late, and the early part of the summer cool. During the second week in July, 1904, I made borings to a depth of 9 feet in the most exposed situations that I could find. There was no trace of frost, although the soil at a depth of 6 feet was distinctly chilly to the touch. Both above and below, it was decidedly warmer. In the first part of April, 1905, I made numerous borings until the auger had passed through the frozen soil. In the exposed gardens and fallows the frost had penetrated from 4½ to 5½ feet. On the stubble it had reached a depth of only 3½ feet. The subsoil of the prairie was so dry that I could not decide how far the ground was frozen. It is probable that the frost is all out of the ground by the 1st of July of every summer, unless it be on the edges of the forest country, where the drifting leaves serve to prevent the thawing of the soil.

The fertility of the soil is apparent to any one who visits the Province of Saskatchewan at the close of a favorable crop season. It is a well-recognized fact, however, that in regions where the normal precipitation is very small, abundant crops are produced even on very coarse sands in those seasons during which the rainfall is unusually heavy and well distributed. Evidence that the soil of southern Saskatchewan is characterized by the ability to produce a high average yield of wheat, oats, barley, and potatoes for many years in succession without the application of any fertilizers or even the growing of leguminous crops is furnished by the annual reports of the Indian Head experimental farm, which has been maintained by the Canadian government since 1888. Experimental farms are maintained by the same government at four other places—Nappan in Nova Scotia, Ottawa in Ontario, Agassiz in British Columbia, and Brandon in Manitoba. The first three represent humid climates with a heavy winter precipitation, while the farms at Brandon and Indian Head are in the region of very light winter precipitation. The climate at Brandon is very similar to that at Indian Head except that the precipitation is somewhat heavier and the summer temperature somewhat higher. Part of the Brandon experimental farm is on the upland and part in the valley of the Assiniboine River, the latter being subject to occasional inundations and also, probably, to more or less subirrigation. No distinction has been made in most of the reports of the farm regarding the data inadmissible in a study of the relation of crop yield to rainfall.

In illustration of the above-mentioned characteristics, the yield of the 12 best-adapted varieties of wheat, oats, barley, potatoes, etc., during a period of from four to nine years that they have been under trial at the five Canadian farms, where the conditions of experiments are similar, are given in Table I.

TABLE I.—*Average yields of the best-adapted varieties of various crops at the five Canadian experimental farms.*[a]

Crop.	Number of varieties grown.	Averages for years 1895–1903.						Average at Indian Head in 1901.
		For the five farms.	For Ottawa farm.	For Nappan farm.	For Brandon farm.	For Indian Head farm.	For Agassiz farm.	
Oats, bushels[b]	12	76.2	64.5	77.2	88.5	94.5	67.5	132.8
Barley, 2-rowed, bushels	6	45.5	45.3	45.1	46.0	56.2	43.3	60.0
Barley, 6-rowed, bushels	6	50.8	50.1	50.6	56.0	60.5	45.9	64.0
Wheat, spring, bushels	12	34.3	28.0	36.9	35.9	42.2	34.9	63.2
Peas, bushels	12	35.7	33.6	31.9	47.3	41.5	37.5	57.7
Maize, green, tons	6	19.4	23.1	18.8	19.6	14.6	22.9	25.2
Turnips, tons	6	31.5	34.2	39.9	25.1	22.3	39.7	37.5
Mangels, tons	6	31.7	39.1	38.0	31.1	22.6	34.3	29.3
Carrots, tons	6	22.0	30.7	22.3	14.3	12.2	31.1	12.6
Sugar beets, tons	4	24.5	28.8	27.2	19.4	11.2	17.0	27.7
Potatoes, bushels	12	377.9	399.2	387.0	395.3	433.6	371.0	620.5

[a] Some of the varieties in the averages have been under trial only four years, but most of them have been tested for nine years.

[b] Bushels of 34 pounds.

It will be seen that the average yield of wheat, oats, barley, and potatoes is higher at Indian Head than at the other four farms. The yields of the same crops in 1901 are given in illustration of the effect of an unusually favorable season at Indian Head. It is important to note that only in the case of peas, in addition to the four crops mentioned, does the Indian Head farm give heavy yields. The other crops included in the table, as well as hay, produce more heavily at each of the other four farms.

The soil of the Indian Head farm is typical of that of the greater portion of the spring-wheat region of Saskatchewan. The surface soil consists in some places of bowlder clay, and in others of a very heavy lacustral deposit that had formed in the bottom of a large shallow glacial lake. The lacustral clay was not found to exceed more than 3 feet in depth on the Indian Head farm, while at Moose Jaw it exceeded 9 feet in depth in all places where samples were taken. The lacustral clay was everywhere underlaid by bowlder clay. (See Table II.)

The chemical composition of the subsoil of the district gives every evidence of the aridity of the climate, the percentage of carbonates and soluble salts being very high.

The amount of carbonates in the surface soils is in all cases less than that in the subsoil. The subsoil, judged by the content of carbon dioxid, is of two distinct types, the one carrying from 7.5 to 12 per cent and the other from 1.25 to 4 per cent. These two types of subsoil differ in physical as well as in chemical properties. The first bowlder clay carries stones and bowlders, while in the second, a clay of lacustral origin, only an occasional small stone is found. The former rapidly disintegrates in contact with water, from 1 to 3 hours' boiling being sufficient to reduce it to clean, single grains, as observed under the microscope, while the latter when treated with water breaks up into small aggregations which, when rubbed with a stirring rod, become like putty, and which require from 30 to 36 hours' boiling with water to completely resolve into their individual soil particles.

The till, or bowlder clay, possesses much lighter color, both in the wet and in the dry condition, than the lacustral clay. The dried lumps of the former can be crushed between the thumb and finger, while those of the latter can not. As is shown by the table of mechanical analyses, the till is much richer in sand and poorer in clay particles than the lacustral deposit; the proportion of silt in the two is about the same. The difference in appearance of the two types of soil when removed from fields in which a crop of grass or some cereal has just reached maturity is very marked, the till being brought to the surface by an augur in the form of powder, resembling wood ashes, while the other forms a more or less coherent mass of small aggregations. One of the most important and characteristic properties in which the two types differ is the hygroscopic coefficient of the subsoil. The surface soil, on account of the humus it contains, possesses a high coefficient, no matter to which type it belongs. In the case of the subsoils that of the till has a value between 3.9 and 6, and that of the lacustral clay lies between 10.3 and 14.7. A careful examination of the samples whose coefficient lay between 5.8 and 10.8 showed that they were mixtures of the two types.

TABLE II.—*Mechanical analyses of specimens of the two soil types at the experimental farm at Indian Head, Saskatchewan.*

Character of soil.	Bowlder clay.	Lacustral clay.
	Per cent.	*Per cent.*
Gravel, 2 to 1 mm	1.7	0.0
Coarse sand, 1 to 0.5 mm	5.2	0.01
Medium sand, 0.5 to 0.25 mm	5.6	0.01
Fine sand, 0.25 to 0.10 mm	14.1	2.2
Very fine sand, 0.10 to 0.05 mm	12.3	6.7
Coarse silt, 0.05 to 0.016 mm	16.2	19.0
Fine silt, 0.016 to 0.005 mm	19.5	22.6
Clay, less than 0.005 mm	26.1	48.2
Total	100.7	98.8

In most of the fields examined on the Indian Head experimental farm the surface soil seemed to consist of a mixture of the two types. This is probably due to a combination of three causes, viz, (1) high winds, which blow soil from the surface of one type over the surface of the other; (2) the action of the plow where the layer of the lacustral clay is very shallow; (3) the work of burrowing animals which carry bowlder clay subsoil to the surface and deposit it upon the lacustral clay.

I made analyses of samples of soil taken from each of the first 6 feet of a field of 10 acres that had never been fertilized. The field had been in fallow in 1904, and in 1905 bore a crop of spring wheat yielding on an average per acre over 46 bushels. The samples were secured in November, 1905. The amount of nitrogen in the surface foot of soil was large, amounting to about one-fourth of 1 per cent. The percentage of potash was high, and that of phosphoric acid was fairly high at all depths. The percentage of calcium carbonate below the first foot was very high, varying from 15 to 20 per cent. While the chemical analysis indicates this to be a fertile soil, there is nothing in its chemical composition to explain the remarkable crop yields that have been obtained.

There can be no doubt as to the semiaridity of the climate of southern Saskatchewan when an examination is made of the records of the meteorological stations which have been maintained there for the past twenty-three years by the Canadian government. A station has been maintained on the Indian Head farm since 1890, in latitude 50° 28′ and longitude west 103° 40′. It is 1,924 feet above sea level.

TABLE III.—*Rainfall and snowfall at Indian Head, Saskatchewan, in inches.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total rainfall.	Total snowfall.	Total precipitation (10 inches snow = 1 inch rain).	Total rainfall of crop season.
1890	.....	.....	.....	0.51	0.80	4.48	3.01	2.16	1.05	1.37	.....	.....	15.40	......	......	10.09
1891	.....	.....	.....	.00	.97	6.19	3.84	2.14	.86	.03	.....	.....	14.03	......	......	13.14
1892	.....	.....	.....	.60	.82	2.59	1.09	.89	.93	1.40	.....	.....	6.92	......	......	5.10
1893	.....	.....	.....	.00	3.17	4.60	2.12	.12	.10	.90	.....	.....	11.01	......	......	[illegible].89
1894	.....	.....	.....	1.20	.30	.80	.57	1.03	.....	.....	.....	.....	3.90	......	.....	2.87
1895	.....	.....	.....	.00	2.10	3.95	3.82	.60	1.60	.10	0.90	0.90	12.17	......	......	10.37
1896	.....	0.05	0.00	1.75	2.83	4.32	1.90	1.39	.60	.00	1.40	.15	11.19	......	......	10.23
1897	0.25	.50	.30	.00	.00	11.20	1.52	1.30	.20	.80	1.30	.00	13.45	27.5	16.20	12.74
1898	.40	.30	.60	1.05	.50	4.14	3.36	4.00	4.03	1.85	.40	.00	18.03	26.0	20.63	9.75
1899	.40	.00	1.00	.50	2.15	5.24	.40	.90	1.15	1.20	.30	.40	9.64	41.0	13.74	9.19
1900	.10	.55	.45	.27	.80	.65	1.73	4.85	3.81	.50	1.00	.80	12.21	32.5	15.46	3.45
1901	1.50	.35	.20	1.71	.87	5.63	5.82	.00	5.10	1.58	.00	.50	17.76	55.0	23.26	12.38
1902	.00	1.40	1.35	.87	3.87	4.96	.67	.57	.42	.00	.60	1.30	10.71	53.0	16.00	9.78
1903	.40	.10	.35	.16	4.08	1.29	4.23	4.16	1.26	.40	1.10	1.40	15.48	34.5	18.93	12.50
1904	.85	2.25	3.30	.54	1.94	2.76	3.81	1.17	1.79	.32	.38	1.00	11.92	81.3	20.05	8.74
1905	.25	.45	.91	.57	3.34	5.16	2.47	2.23	5.00	.54	.....	.....	19.31	......	......	12.49
Average	.41	.61	.84	.61	1.78	4.25	2.52	1.72	1.74	.73	.74	.64	12.69	......	16.55	9.54
Lowest	.00	.00	.00	.00	.00	.65	.40	.00	.10	.00	.00	.00	3.90	26.0	......	2.87
Highest	1.50	2.25	3.30	1.75	4.08	11.20	5.82	4.85	5.10	1.85	1.40	1.40	19.31	81.3	......	13.14

In Table III the rainfall and snowfall at Indian Head are given in so far as these are available. There is no record of the rainfall at this station prior to 1890, and the snowfall previous to 1895 was not recorded. The records of the neighboring stations of Regina and Qu'Appelle, dating from 1885, indicate that the climate from 1885 to 1890 was similar in character to that from 1890 to 1895. However, the precipitation records of these stations should not be used in seeking a relation between rainfall and crop yield at Indian Head. There may be enough difference in the rainfall at two different places 20 miles apart to account for a poor crop at one place and a good crop at the other. Accordingly, in the consideration of the crop yields at Indian Head I use only the data for the years beginning with 1890.

Practically the whole of the precipitation from November to March, inclusive, is in the form of snow. It seems improbable that the snow which falls between the time when the ground freezes in the autumn and the time when it melts in the spring has much influence on the relative yield of spring-sown cereal crops except in so far as it favors germination of the seed. The snowfall is regarded in the table as melted snow (10 inches of snow equals 1 inch of rain). Over half the rain falls during the months of June and July, and over three-fourths between the time of seeding and that of harvest. There is, however, great variation from year to year in the precipitation of any one month, as is shown in the last two lines of the table.

The heaviest rainfall of any crop season occurred in 1891, it being 13.14 inches, closely followed by that of the years 1897, 1901, 1903, and 1905, when it was between 12 and 13 inches. The lightest rainfalls occurred during the crop season of 1894 (2.87 inches), 1892 (5.10 inches), and 1900 (3.45 inches for crop season of wheat, 4.18 inches for that of oats, and 5.86 inches for that of barley). In 1892 and 1894 the rainfall of the crop season was the same for all three crops. The yields of field crops of wheat, oats, and barley, sown on fallow in these dry years, were as follows:

TABLE IV.—*Yields at Indian Head during the three dry years 1892, 1894, and 1900.*

Year.	Rainfall of crop season.	Wheat.		Oats.		Barley.	
	Inches.	*Bu.*	*lbs.*	*Bu.*	*lbs.*	*Bu.*	*lbs.*
1892	5.10	29	9	42	..	45	9
1894	2.87	16	46	26	17	16	29
1900	3.45	15	43	55	..	35	24

The summers of 1894 and 1900 were characterized by high temperatures with hot winds. In the summer of 1894 the temperature often reached 95° to 100° F. In 1900 on June 21, 22, and 23 the thermometer registered maximum temperatures of 101.5°, 106°, and 103°. From Table IV it will be seen that high temperatures are not uncommon at Indian Head. The instances of unusually heavy precipitation in April have been in the form of snow, and those in October in that of rain. Rains of such a torrential character as to cause a considerable run-off from level plowed fields have been rare, those of June, 1897, being probably the only ones during the past seventeen years. The precipitation of this summer was so unusual that I quote the following description from the annual report of the station:

> In the season of 1897 less than 1 one-hundredth of an inch of rain fell between the 1st of April and the 14th of June. Seeding commenced on the 16th of April and continued without intermission until completed. High and continuous winds were prevalent during the last week in April, the whole of May, and from the 1st to the 15th of June. On June 14 0.6 inch of rain fell; on the following day within nine and one-half hours 6.6 inches fell. Twenty-seven hours after this downpour ceased a rain began, lasting two hours, during which 0.9 inch fell, making 10.6 inches within five days. The greater portion of this rain flowed over the land to the coulées, thence to the Qu'Appelle River. The rainfall amounted to 2.12 inches between June 17 and harvest, which began on August 12 for barley, August 16 for wheat, and August 26 for oats. This amount was distributed as follows: June 27 (0.6 inch), July 4 (0.5 inch), 5 (0.1 inch), 7 (0.15 inch), 8 (0.4 inch), 10 (0.2 inch), and 23 (0.17 inch). No rain fell during August previous to the 26th.

In Table V are given the mean monthly temperatures for both North Platte and Indian Head. The differences in the winter time are great, but those in the summer are very much smaller.

TABLE V.—*Average mean temperature at Indian Head, Saskatchewan, and at North Platte, Nebr.*

Month.	Indian Head.	North Platte.	Difference.
	°F.	*°F.*	*°F.*
January	4	20	16
February	5	25	20
March	17	35	18
April	41	49	8
May	54	58	4
June	65	68	3
July	68	74	6
August	66	71	5
September	58	62	4
October	42	50	8
November	22	35	13
December	12	27	15
Year	38	48	10

In Table VI we have the annual maximum and minimum temperatures at Indian Head. While the minimum temperature is very low, the maximum temperature is generally quite high, sometimes exceeding 100° F.

TABLE VI.—*Maximum and minimum temperatures at Indian Head, Saskatchewan, from 1890 to 1906, inclusive.*

Year.	Maximum.	Minimum.
	° *F.*	° *F.*
1890	95	−40
1891	85	−42
1892	98	−44
1893	100	−52
1894	100	−39
1895	95	−38
1896	96	−38
1897	92	−48
1898	99	−32
1899	95	−43
1900	106	−37
1901	94	−37
1902	90	−35
1903	92	−42
1904	92	−47
1905	88	−43
1906	99	−38

In Table VII we have the mean monthly precipitation at Indian Head and at North Platte. The precipitation is similarly distributed, but is higher at North Platte.

TABLE VII.—*Average precipitation at Indian Head, Saskatchewan, and at North Platte, Nebr., from 1890 to 1906, inclusive.*

Month.	Indian Head.	North Platte.
	Inches.	*Inches.*
January	0.41	0.47
February	.61	.42
March	.84	.75
April	.61	2.17
May	1.78	2.70
June	4.25	3.42
July	2.52	2.74
August	1.72	2.42
September	1.74	1.28
October	.73	.98
November	.74	.35
December	.64	.57
Total	16.55	18.27

The Indian Head experimental farm consists of 682 acres. In 1882 a large farming company broke up 640 acres. From that time until the Canadian government took possession in 1888 the entire section was in crop each year. Mr. Mackay, a farmer living in the district since 1882, was placed in charge of it as superintendent and still continues in that position. In his annual report for 1889 he stated that experience had shown that there was only one successful way in which crops could be raised on the prairies of western Canada, and that was by the use of the summer fallow for the purpose of storing moisture:

> In this portion of the territories, at least, every settler knows the importance of properly preparing his land. For several years after the country became

open for settlement everyone imagined that grain would grow, no matter how put in, but now the man is devoid of reason who thinks he is sure of a crop without any exertion on his part. It is true that we have had one year since 1882 that required little or no preparation to give a most abundant crop, but too many know how little was received in the remaining years by poor cultivation.

Our seasons point to only one way in which we can in all years expect to reap something. It is quite within the bounds of probability that some other and perhaps more successful method may be found, but at present I submit that fallowing the land is the best preparation to insure a crop. Fallowing land is not required in this country for the purpose of renovating it, as is the case with worn-out lands in the east, and it is a question yet unsettled how much or how little the fallows should be worked, but as we have only one wet season during the year, it is found beyond doubt that the land must be plowed the first time before this wet season is over if we expect to reap a crop the following year. This wet season comes during June or July, at a time when every farmer has little or nothing to do, and then this work should be done. Usually seeding is over by the 1st of May, and to have the best results the land for fallow should be plowed from 5 to 7 inches deep as soon after this as possible. Land plowed after July is of no use whatever, unless there is rain in August, which very seldom comes to any great extent. A good harrowing should succeed the plowing, and all weeds or volunteer grain should be kept down by successive cultivations.

Almost the same statements appear in Mr. Mackay's last annual report, that of 1905:

It is very gratifying to know that throughout the territories summer fallowing is rapidly becoming general. No matter where farming is carried on, the farmers realize that to be sure of a crop they must prepare a portion of their land the year before the crop is grown; and apart from the value of the stored moisture there is the inestimable advantage of keeping weeds from overrunning the farm. The true worth of properly prepared fallows has been clearly demonstrated in past years in every grain-growing district of Assiniboia.

As has been pointed out in my previous reports, early and thorough work on fallows is absolutely necessary to success.

The minister of agriculture of the Province of Saskatchewan has recently stated in a published address that successful wheat growing in Saskatchewan depends upon the intelligent use of the fallow:

If one is to attain the greatest success in the cultivation of wheat on the western prairie, there are at least three outstanding questions that demand intelligent study and prompt action, and these are soil moisture, good seed, and weeds.

Taking the average year and the average prairie, soil moisture is by far the most important question that should engage the active attention of the farmer. Because of this, bare summer fallowing is becoming, and, indeed, in many parts has already become, the very foundation upon which successful wheat culture is based and profitably carried on. True, there are many dissenters from this, but these are invariably from localities where the rainfall is more abundant and fall plowing has met with a good measure of success.

During the past twenty-five years there has not been sufficient moisture, taking one year with another, to grow a crop each consecutive year; hence the necessity of stopping every third or fourth year and catching up, as it were, with the supply of moisture that can be stored up in the soil during a season of bare fallowing.

The practice of summer fallowing is usually associated in the popular mind with the restoration of fertility: but not so in the West. Conservation of soil moisture is the primary object of bare fallowing.

The crops that have been found to regularly reach maturity and to be well adapted to the climate are spring wheat, oats, barley, peas, flax, buckwheat, native grasses, brome-grass, potatoes, and field roots. Red and alsike clovers do well when partially protected by snow during the winter. Alfalfa in field lots has not as yet, on account of lack of inoculation, had a thorough trial. Winter wheat has usually been entirely destroyed by the alternate thawing and freezing during April. Early varieties of Indian corn do not usually mature seed, but they are far enough advanced before the advent of frost to make good ensilage.

The crop season at Indian Head may be considered to extend from the time that the soil is sufficiently thawed on the surface to permit of the use of drills or harrows until the grain sown in reasonable season is ripe. Frequently the wheat sown late is caught by frost. The earliest recorded date of the beginning of seeding at Indian Head is March 22, 1894, and the latest, with probably the exception of this year, May 7, 1901. The present year shows a very late beginning of seeding, the bulk of the wheat crop having been sown between May 15 and May 31. The earliest harvest on record, namely, that of oats, began July 25, 1894, and the latest, that of wheat, on September 4, 1891. The average date since 1889 of the beginning of harvest in the case of barley is August 17: of oats, August 20: and of wheat, August 21. The growth of cereals in Saskatchewan is not nearly so rapid, in comparison with that of other places, as is popularly believed. The average length of time from seeding until harvest for the four grain crops is greater at Indian Head than at Brandon, Ottawa, or Nappan in Nova Scotia, as shown in Table VIII.

TABLE VIII.—*Average length of time from seeding until harvest at different experimental farms in Canada.*

Location of farm.	Barley.	Oats.	Wheat.	Peas.
	Days.	*Days.*	*Days.*	*Days.*
Indian Head	98	110	127	116
Brandon	92	105	118	120
Ottawa	97	110	117	116
Nappan	93	109	114	111
Agassiz	106	118	118	122

The length of the day in the summer time is not so remarkably long, as is evident when it is remembered that London is farther north than Indian Head. It is true that in the Peace and Slave river districts the night is short, but these are several hundred miles north of where wheat growing is as yet practiced on any considerable scale.

As the greater portion of the farm at Indian Head is used either in experimenting with different varieties of cereals, grasses, and legumes or for the production of seed of the best-adapted varieties for government distribution throughout the western provinces, each grain crop is usually followed by a year of clean cultivation, to destroy all weeds, grasses, and especially volunteer grain. The year of clean cultivation, termed summer fallow, consists of deep plowing in May or June, followed by three or four harrowings during the summer. In the ensuing spring grain is drilled into the soil without preliminary preparation. Corn and root crops are preceded by, but not followed by, fallow. When the soil has been cultivated long enough to cause it to drift during high winds, the land is seeded with brome-grass or western rye-grass, and after two or three years is treated like virgin prairie sod. When the year of fallow has been followed by more than two crops of grain in succession, the yield of the third and subsequent crops has usually been so much smaller than when the land has been fallowed every third year that the practice is considered unprofitable. In general, however, the farmers in Saskatchewan employ the fallow only every fourth or fifth year, and then carry it out so poorly that at the end of July, in 1904, very few properly worked fallows were to be seen in a journey of several hundred miles through the grain-producing country.

In Table IX is shown the yield of wheat, oats, and barley both on fallow and on stubble since 1889 at Indian Head.

TABLE IX.—*Yield per acre of cereal crops at Indian Head, Saskatchewan, on fallowed land and on stubble field.*

Year.	On fallow.			On stubble.			Excess due to fallowing.				Rainfall of previous autumn.
	Wheat.	Oats.	Barley.	Wheat.	Oats.	Barley.	Wheat.	Oats.	Barley.	Average.	
	Bush.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Inches.*
1890	35.3	....	....	....	....	....	....	....	....	....	....
1891	49.2	83.6	47.1	....	....	....	....	....	....	....	....
1892	29.2	42.0	45.2	....	....	....	....	....	....	....	....
1893	36.1	77.0	46.8	27.9	63.2	40.4	29	22	16	22	3.22
1894	16.8	26.5	16.6	7.5	10.1	6.8	124	162	144	143	1.12
1895	41.3	104.6	55.1	28.1	37.6	31.7	47	178	74	100	1.03
1896	40.1	95.5	57.8	29.7	....	....	35	....	....	35	1.70
1897	30.9	66.8	49.0	25.3	....	....	22	....	....	22	.60
1898	29.1	82.7	41.8	....	....	....	....	....	....	....	2.30
1899	32.4	75.8	46.8	28.9	....	....	12	....	....	12	8.88
1900	15.7	55.0	35.5	5.4	10.4	7.6	191	429	365	329	2.35
1901	41.7	100.0	52.2	38.4	90.0	49.2	8	11	5	8	9.16
1902	33.4	76.0	58.2	25.5	43.6	25.5	31	74	128	111	6.68
1903	35.8	94.0	54.6	15.4	43.8	18.7	132	115	192	146	.42
1904	39.4	75.5	43.1	30.3	62.1	36.8	30	21	17	23	1.66
1905	40.0	90.9	63.3	23.3	47.4	43.5	72	92	46	70	2.01

In the case of several years there evidently was no wheat sown on stubble at the experimental farm. In general there is little difference between the average yield on all plats and that on the fields, the greater adaptability of the varieties sown as field crops compensating for the usual advantages enjoyed by the plat experiments, on which many varieties are sown that are ill adapted to the climate. You will notice that in all cases the high yields have been obtained from the fallows. The year 1905, while not giving the highest yields at Indian Head, was in many respects ideal, and the relation of the yield of wheat on stubble to that on fallow may be considered a normal one.

When the annual yields are compared with the precipitation of the corresponding crop season, it is to be seen that the yield of grain on fallow varies in general with the rainfall of the crop season, but shows a closer dependence upon the total available moisture, which I will speak of a little later. The greatest difference between the yields on fallow and on stubble is to be observed in the case of those seasons that have been preceded by a normally dry autumn. In the case of the two years 1898 and 1900, in which the rainfall following the ripening of crops amounted to approximately 9 inches, the yields of the following years, 1899 and 1901, were about the same on stubble as on fallow. The explanation of the disappearance of the difference between stubble and fallow when the season had been preceded by a wet autumn is the following: During the summer large quantities of nitrates are formed and are stored up within reach of the plant roots, in the case of the fallow fields, so that crops on fallow under normal conditions are supplied with a large quantity of nitrates and an abundance of moisture, while those on stubble have neither such a supply of nitrates nor much moisture. A heavy rainfall in autumn carries the nitrates in the fallow fields below the reach of the plant roots and at the same time charges the stubble fields with moisture, thus putting the stubble in a condition similar to that of the fallow as regards water and nitrates.

A very light rainfall during the months of July and August when the rainfall of May and June has been abundant causes a comparatively light yield of straw, together with a good yield of grain, as shown by Table X.

TABLE X.—*Average yield of the field lots of grain at Indian Head, Saskatchewan, in years in which the rainfall of July and August was light. 1892 to 1902, inclusive.*

Year.	Rainfall of April, May, June.	Rainfall from July 1 to harvest.	Yield.					
			Wheat.		Oats.		Barley.	
	Inches.	*Inches.*	*Bu.*	*lbs.*	*Bu.*	*lbs.*	*Bu.*	*lbs.*
1892	4.01	1.98	29	12	42	16	46	32
1893	7.77	2.24	36	6	67	1	45	36
1896	8.90	3.29	36	35	96	27	59	31
1897	11.20	1.52	30	53	67	24	50	27
1899	7.89	1.80	32	27	76	26	48	15
1902	9.70	1.24	33	25	76	33	44	23

I have been unable to find any connection between the winter temperatures and the yields of the following season.

By far the most interesting results of my investigations are those dealing with the amount of moisture existing in what may be called an available form in the grass, fallow, and stubble fields, as determined foot by foot to a depth of 6 feet. In Table XI there is shown the number of tons of free water in each acre-foot of different fields at Indian Head and Moose Jaw.

Table XI.—*Available moisture in fallowed fields at Indian Head and Moose Jaw, Saskatchewan, compared with that in fields that have just brought a cereal or grass crop to maturity. The water is expressed as tons per acre-foot.*

Field.	Date.	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.	Total.
		Tons.	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*
A	July 25, 1904	127	75	97	112	84	101	596
A	September 4, 1905	268	157	167	177	170	152	1,091
	Excess in second year	141	82	70	65	86	51	495
B	July 25, 1904	291	184	196	199	236	194	1,800
B	September 5, 1905	179	95	77	69	167	211	798
	Excess in fallow	112	89	119	130	69	17	502
D	July 25, 1904	350	272	279	216	144	....	1,261
D	September 5, 1905	270	158	144	97	182	....	734
	Excess in fallow	80	114	135	119	38	....	527
F	September 9, 1905	162	412	360	266	236	231	1,667
G	September 9, 1905	144	99	104	194	213	228	982
	Excess in fallow	18	313	256	72	23	3	685

The samples were obtained by the writer in July, 1904, and in September, 1905, a 1½-inch extension auger being used for the purpose. A large number of samples would have been desirable, but the difficulty of carrying on the investigations when the drying of the samples had to be done at a distance of over 1,000 miles from the fields limited the number of determinations. That the samples in which the water was determined were fair specimens of the various fields at the different depths was confirmed by the careful examination on the spot of the soil from similar depths in various parts of the fields. The samples are the average of the foot section from two or more holes in the same field, the soil being weighed as soon as removed and placed in light cotton sacks of known weight and later dried at 100° C. Duplicates of each sample were taken.

A whole series of samples was secured for me by Mr. Reynolds, accountant at the Indian Head farm, in November, 1904, just before the ground froze. It was hoped that these would yield valuable information as to the distribution of moisture in the subsoil at the beginning of winter. While the samples were being brought to an air-dry condition at Indian Head preparatory to shipping, they were so tampered with that many of them were rendered of no value. Accordingly the whole series has been omitted from consideration.

The distance to which the bare soil at the edges of the fields exerted an influence upon the crop was readily seen in the case of grass fields, where the dark-green color and rank growth at the extreme edge stood in sharp contrast with the light-green color and weaker growth of the plants that were from 2 to 3 feet away. Through this short distance there was a gradual change in the appearance of the grass, but the plants farther in seemed to derive no benefit from the bare edges. In the case of each field all holes were bored at a distance of not less than 10 feet (usually more than 12) from the edge. Those from which samples for any one field were obtained were from 6 to 20 feet apart, it being necessary in most cases to make several borings before reaching the desired depth, the stones of the bowlder clay stopping the auger. In all the fields, while the depth to which the moisture from recent rains had penetrated varied somewhat, the succession of changes in the moisture content of the soil below the third foot was similar in all parts of the same field. In two fields of bromegrass all borings were stopped by stones within 3 feet of the surface.

Field A was seeded with western rye-grass (a native) in 1901, and has been cut for hay every year since, being mown about July 23, 1904, and July 13, 1905. No plants other than those of rye-grass were found within a distance of 3 feet of any of the holes. The growth of the grass in 1904 showed that it had suffered from an insufficient supply of water. Between the eighteenth and sixtieth inches the moisture content had probably been reduced to its minimum. From the sixtieth to the seventy-second inch the moisture content rose rapidly, the soil of the first 6 inches resembling wood ashes, while that of the last 6 inches was moist and sticky. In 1904 the rainfall between June 12 and July 1 amounted to only 0.39 inch. From the latter date until the samples were taken it amounted to 1.45 inches, occurring as follows: July 1, 0.1 inch; 12, 0.22 inch; 13, 0.93 inch; 16, 0.05 inch, and 17, 0.15 inch. The moist condition of the surface foot indicated that the water from the rain of July 13 was still largely retained at the time of sampling. No data are available to indicate to what extent the moisture content of the surface foot may be reduced by rye-grass. In 1905, between July 15 and the time of sampling, 4.26 inches of rain fell. Assuming that on the latter date the soil was as dry as on July 25, 1904, and that the weight of an acre-foot of dry soil is 3,348,000 pounds, the soil moisture available for rye-grass has been increased by 495 tons per acre when the rainfall amounted to 484 tons per acre.

Field B, which is just north of A, the two being separated by a roadway, had produced about 10 tons per acre of carrots in 1903 and was in fallow in 1904. In 1905 it bore a very heavy crop of oats (8,280 pounds of dry matter per acre). These had been cut a few days previous to the sampling. The straw, which was very heavy, had been badly lodged. At all depths in 1904 the soil was very moist, but in 1905, while the recent rain of August 30 and 31 (1.28 inches) had moistened the soil to a depth of from 18 to 30 inches, the deeper portions of the subsoil resembled the subsoil of the rye-grass field in the preceding year. It was driest at a depth of 30 to 40 inches, gradually becoming moister from the fortieth to the sixtieth inch, and rapidly from the sixtieth to the seventy-second. As the recent rain had raised the moisture content of the first 2 feet, an allowance should be made in estimating the lowest limit of soil moisture permitting of the growth of oats. This may be safely placed at 18 per cent for the first foot. A pot experiment in which barley was grown in this surface soil showed that the plants wilted when the water content of the soil fell to 18 per cent. There was a difference of 502 tons of water per acre to a depth of 6 feet between the two dates of sampling, equivalent to 4.5 inches of rain. This probably represents the approximate storage capacity for water of this type of soil in the case of an oat crop.

Field C, which was about 300 yards south of A, had been in fallow in 1898, in wheat in 1899, in barley in 1900, in oats in 1901, in wheat in 1902, and in barley in 1903. It bore a crop of oats at the time of sampling in 1904. The crop, which at the time was in head, was very short in the straw and somewhat yellow in color, this field being selected for sampling because it showed the effects of the drought more than any other field bearing a cereal crop on the farm. The soil appeared about equally moist at all depths below the surface foot in 1904, while in the following year the moisture was lowest at a depth of from 30 to 42 inches, increasing gradually from the forty-second to the sixtieth inch and seeming uniform between the sixtieth and the seventy-second inch. The crop of wheat, which was in shock at the time of sampling in 1905, yielded, as determined later, 18 bushels and 24 pounds of grain and 1,056 pounds of straw to the acre.

Field D, which lay adjoining C on the south, had been alternately in wheat and in fallow since 1898, being in fallow in 1904 and in wheat in 1905. At the time of sampling in the latter year the crop was in shock. The soil was moist at all depths in 1904 and to a depth of about 2 feet in 1905. In the latter year, from the twenty-sixth to the forty-second inch it was very dry but became gradually moister from the latter depth to the sixtieth inch, the sixth foot seeming very uniform in moisture. The straw, which had not lodged, had been cut to leave a stubble from 8 to 10 inches long. The moisture in the upper 3 feet had evidently not been reduced to its minimum. As the soil of the field to this depth was in origin and character similar to that of field F, while the latter had not received so much rain during the later portion of the growing season, field F is to be considered as better representing the lower limit of moisture for this type of soil. The soils from fields D and F to the depth of 3 feet are very similar in appearance and texture and have practically the same hygroscopic coefficient, viz, 13.0. Field D contained on July 25, 1904, within the first 5 feet of soil, 527 tons of water more than on September 5, 1905. The yield of this field for 1905 was 32 bushels and 46 pounds of grain and 3,724 pounds of straw.

Field E, 150 yards northwest of B, had been in fallow in 1904. At the time of sampling in 1905 the crop of wheat was in shock. It had lodged badly and the stubble had been left 10 to 12 inches long. The yield of grain was 15 bushels per acre and of straw 6,000 pounds per acre. The soil was moist to a depth of 18 inches on a very low ridge that traversed the field from north to south and to a depth of 24 to 36 inches at the foot of the ridge. At depths below the third foot no difference was observed between the moisture of the soil on the ridge and that in the depression. It was very dry to a depth of 42 inches, becoming gradually moister to the sixtieth inch, and seeming uniform throughout the sixth foot.

F and G were adjoining fields on the same farm, 1 mile south of Moose Jaw. These fields were selected because they promised to give the extremes of moisture, one being an unusually clean summer fallow and the other bearing a very heavy crop of wheat, which was in shock at the time. The soil was typical of a large plain of lacustral origin, the soil of which is very uniform over a great area, the underlying bowlder clay being exposed only in ravines. The uniform character of the soil is well illustrated by the hygroscopic coefficient of the twelve samples. These all lie between 11.4 and 11.8 for the third, fourth, fifth, and sixth foot sections, and a little higher for the first and second foot sections. The rainfall of 1904 at the Moose Jaw Meteorological Station, 1 mile distant, was 7.67 inches, and that of 1905 up to the time of sampling 13.03 inches. The precipitation of the latter year between July 30 and September 9 was only 0.78 inch, distributed as follows: August 1, 0.01 inch; 2, 0.28 inch; 3, 0.18 inch; 15, 0.01 inch; 26, 0.11 inch, and 28, 0.19 inch. With such a small rainfall during the last month of its growth it is probable that the heavy crop on field F, estimated at about 6,000 pounds per acre, had nearly exhausted the surface foot of available moisture before the light showers of August 26 and 28 fell. The fallow field G within the first 5 feet contained 682 tons per acre of free water (equal to 6 inches of rain) more than the adjoining field that had produced a crop. The wheat roots had not drawn as heavily upon the fourth and fifth feet as upon those above, nor had the season's rainfall been sufficiently conserved to raise to near its maximum limit the moisture content of the soil below the third foot in the case of the fallow field. It should be noted, however, that the season of 1905 with an exceptionally well-distributed rainfall had not been favorable for the reduction of the soil moisture to its minimum, and that, further, the previous year had not had a sufficiently heavy rainfall to raise the moisture content of the first 4 feet to its maximum, even if surface evaporation had been entirely prevented. In the case of the fallow field about half the rainfall for the season had been stored, chiefly below the first foot. This amount of water would be sufficient to produce 20 bushels of wheat per acre if no surface evaporation took place and the ratio of grain to straw were 1 to 1.5. The writer determined the ratio of grain to straw (dried at 100° C. in each case) on field F, as well as on an adjoining field of wheat that had also produced wheat in 1904. The ratio of the grain to the straw was 1 to 1.35 on field F and 1 to 1.31 on the stubble field. The stubble, which was about 8 inches long on the latter and 12 inches on the stubble field, was about half as heavy as on field F. The whole crop on this farm consisted of 200 acres on fallow and 200 acres on stubble. The yield of the different fields was not determined, but that from the 400 acres was 12,000 bushels of wheat. The crop on fallow was very uniform, as was also that on stubble. The yields may be considered as 40 and 20 bushels per acre, respectively.

The calculation of the amounts of "available water" given in Table IX was based on the following asumptions:

(1) That the weight of an acre-foot of ground is 3,348,000 pounds.

(2) That the samples secured were representative of the different fields.

(3) That the available moisture is the difference between the total moisture content, as determined by drying at 100° C., and the maximum amount of hygroscopic water that is taken up by a soil when exposed to a saturated atmosphere. The latter, expressed as the hygroscopic coefficient (the amount of moisture held by 100 grams of dry soil, calculated as dried at 100° C.), was determined by Hilgard's method.

The first two assumptions may safely be considered as approximately correct; a difference of 10 to 15 tons of water per acre-foot may well be attributed to the lack of accuracy in the methods and in the assumptions. Differences of 50 to 100 tons of water per acre-foot can not justly be so explained. In the case of nearly all moisture determinations hitherto published the hygroscopic coefficient of the soil has not been determined, thus rendering the results of little value. Only the difference between the total water and the hygroscopic water (in a saturated atmosphere) is, even under the most favorable circumstances, available for plant growth. The hygroscopic water in air-dry soil is not a constant, as it depends both upon the temperature and upon the humidity of the atmosphere with which it is in contact. The hygroscopic coefficient, on the other hand, is, according to Hilgard, a constant for a definite temperature, varying only by small fractions for temperatures between 7° and 23° C. It is also a critical point in relation to plant growth. Pfeffer states that "plants slowly die if the leaves are freely exposed while the roots and soil are kept in saturated air." If the leaves as well as the roots and soil are kept in a saturated atmosphere the plants live but make no growth. As all growth ceases and, except under the unusual circumstance of the air being saturated with water vapor, plants begin to die as soon as the point is reached at which the soil contains only its maximum amount of hygroscopic water, there is no possibility of any hygroscopic water being used for the growth of the plants. Very few data are available showing how near to the hygroscopic moisture the water content of a soil may be reduced by growing plants. Only under very favorable atmospheric conditions can a plant continue its normal development after the water content is reduced to near the hygroscopic coefficient.

As illustrations of how little value determinations of the total water content of soils usually have when the hygroscopic coefficient is not determined, the data in Tables XII to XVIII are presented:

TABLE XII.—*Amount of total moisture in different fields expressed as percentage of dry soil.*

Depth.	Field A.		Field B.		Field C.		Field D.		Field E.	Field F.	Field G.
	July 25, 1904.	Sept. 4, 1905.	July 25, 1904.	Sept. 5, 1905.	July 25, 1904.	Sept. 5, 1905.	July 25, 1904.	Sept. 5, 1905.	Sept. 5, 1905.	Sept. 9, 1905.	Sept. 9, 1905.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
First foot..	19.0	25.9	29.4	22.4	20.0	28.8	34.4	28.9	26.4	22.2	23.6
Second foot	14.8	20.3	14.9	16.7	22.4	19.8	29.7	22.7	14.8	18.6	36.8
Third foot.	13.9	20.9	16.4	9.2	21.6	10.9	29.5	20.9	15.4	18.0	33.2
Fourth foot	13.6	15.4	17.4	9.6	16.1	17.1	20.3	11.3	13.2	23.5	27.7
Fifth foot..	12.0	15.1	21.8	14.4	15.1	18.4	15.2	16.4	15.6	24.4	26.0
Sixth foot.	15.4	13.6	19.6	17.8	15.9	19.0	19.2	19.2	21.8	25.0	25.2
Average.	14.8	18.5	19.9	15.0	18.5	19.0	24.7	19.9	17.9	21.9	28.7

TABLE XIII.—*Relations of total moisture in first 6 feet of soil to the treatment the field had received.*

Field.	Date.	Water.	Treatment of the field.
		Per cent	
G......	September 9, 1905.....	28.7	Fallow 1905; wheat 1904; wheat or oats 1903.
D......	July 25, 1904...........	24.7	Fallow 1904; alternately in wheat and fallow since 1898.
F......	September 9, 1905.....	21.9	Wheat 1905; fallow 1904; wheat or oats 1903 and 1902.
B......	July 25, 1904...........	19.9	Fallow 1904; carrots 1903; fallow 1902.
D......	September 5, 1905.....	19.9	Wheat 1905; alternately in wheat and fallow since 1898.
C......	.....do.................	19.0	Wheat 1905; oats 1904; barley 1903; wheat 1902; oats 1901; barley 1900; wheat 1899; fallow 1898.
C......	July 25, 1904...........	18.5	Oats 1904; see above.
A......	September 4, 1905.....	18.5	Rye-grass since 1901; cut for hay July 13, 1905; very little growth after mowing.
E......	September 5, 1905.....	17.9	Wheat 1905; fallow 1904.
B......	.....do.................	15.0	Oats 1905; fallow 1904; carrots 1903; fallow 1902.
A......	July 25, 1904...........	14.8	Rye-grass since 1901; cut for hay July 23, 1904.

TABLE XIV.—*Field notes on condition of soil at time of sampling.*

Depth.	Field A.		Field B.		Field C.	
	July 25, 1904.	Sept. 4, 1905.	July 25, 1904.	Sept. 5, 1905.	July 25, 1904.	Sept. 5, 1905.
First foot	Moist	Very moist.	Very moist.	Moist	Dry	Very moist.
Second foot	Dry	Moist	Very moist.	Moist,[a] dry[b]	Moist	Moist.
Third foot	Powder	Moist	Moist	Powder	Moist	Powder.
Fourth foot	Powder	Moist	Moist	Powder	Moist	Powder,[a] moist.[b]
Fifth foot	Powder,[a] very dry.[b]	Moist	Moist	Moist	Moist	Moist.
Sixth foot	Powder,[a] moist.[b]	Moist	Moist	Moist	Moist	Very moist.

Depth.	Field D.		Field E, Sept. 5, 1905.	Field F, Sept. 9, 1905.	Field G, Sept. 9, 1905.
	July 25, 1904.	Sept. 5, 1905.			
First foot	Very moist	Moist	Very moist	Moist	Moist.
Second foot	Very moist	Moist	Moist	Dry	Very moist.
Third foot	Very moist	Dry	Powder	Dry	Very moist.
Fourth foot	Moist	Powder	Powder	Moist	Moist.
Fifth foot	Moist	Moist	Moist	Moist	Moist.
Sixth foot	Moist	Very moist	Moist	Moist	Moist.

[a] Above. [b] Below.

TABLE XV.—*Hygroscopic coefficient of different samples.*

Depth.	Field A.		Field B.		Field C.		Field D.		Field E, Sept. 5, 1905.	Field F, Sept. 9, 1905.	Field G, Sept. 9, 1905.
	July 25, 1904.	Sept. 4, 1905.	July 25, 1904.	Sept. 5, 1905.	July 25, 1904.	Sept. 5, 1905.	July 25, 1904.	Sept. 5, 1905.			
First foot	11.4	9.9	12.0	11.7	12.7	10.9	13.5	12.8	9.5	13.6	13.9
Second foot	10.3	10.9	3.9	11.0	13.2	9.7	13.5	13.1	6.9	12.7	12.2
Third foot	8.1	10.9	4.7	4.6	13.5	4.8	12.9	12.3	5.8	11.8	11.7
Fourth foot	6.9	4.7	5.5	4.5	4.6	5.4	7.4	5.5	5.8	11.9	11.8
Fifth foot	7.0	4.9	7.6	4.4	4.2	5.5	6.6	5.5	5.6	11.7	11.9
Sixth foot	8.9	4.5	8.0	5.2	5.9	4.4	6.6	6.6	10.0	11.4	11.4
Average	8.8	7.6	7.0	6.9	9.0	6.8	10.1	9.3	7.2	12.2	12.1

TABLE XVI.—*Amount of free moisture in different fields, expressed as percentage of dry soil.*

Depth.	Field A.		Field B.		Field C.		Field D.		Field E, Sept. 5, 1905.	Field F, Sept. 9, 1905.	Field G, Sept. 9, 1905.
	July 25, 1904.	Sept. 4, 1905.	July 25, 1904.	Sept. 5, 1905.	July 25, 1904.	Sept. 5, 1905.	July 25, 1904.	Sept. 5, 1905.			
First foot	7.6	16.0	17.4	10.7	7.3	17.9	20.9	16.1	16.9	8.6	9.7
Second foot	4.5	9.4	11.0	5.7	9.2	10.1	16.2	9.6	7.9	5.9	24.6
Third foot	5.8	10.0	11.7	4.6	8.1	6.1	16.6	8.6	9.6	6.2	21.5
Fourth foot	6.7	10.7	11.9	4.1	11.5	11.7	12.9	5.8	7.4	11.6	15.9
Fifth foot	5.0	10.2	14.2	10.0	10.9	12.9	8.6	10.9	10.0	12.7	14.1
Sixth foot	6.5	9.1	11.6	12.6	10.0	14.6	12.6	12.6	11.8	13.6	13.8
Average	6.0	10.9	13.0	8.0	9.5	12.2	14.6	10.6	10.6	9.8	16.6

TABLE XVII.—*Relation of free moisture in first 6 feet of soil to the treatment the field had received.*

Field.	Date.	Water.	Treatment of field.
		Per cent.	
G	September 9, 1905	16.6	Fallow 1905; wheat 1904; wheat or oats 1903.
D	July 25, 1904...........	14.6	Fallow 1904; alternately in wheat and fallow since 1898.
B	.....do	13.0	Fallow 1904; carrots 1903; fallow 1902.
C	September 5, 1905	12.2	Wheat 1905; oats 1904; barley 1903; wheat 1902; oats 1901; barley 1900; wheat 1899; fallow 1898.
A	September 4, 1905	10.9	Rye-grass since 1901; cut for hay July 13, 1905.
D	September 5, 1905	10.6	Wheat 1905; alternately in wheat and fallow since 1898.
E	.....do	10.6	Wheat 1905; fallow 1904.
F	September 9, 1905	9.8	Wheat 1905; fallow 1904; wheat or oats 1903 and 1902.
C	July 25, 1904...........	9.5	Oats 1904; barley 1903; wheat 1902; oats 1901; barley 1900; wheat 1899; fallow 1898.
B	September 5, 1905	8.0	Oats 1905; fallow 1904; carrots 1903; fallow 1902.
A	July 25, 1904...........	6.0	Rye-grass since 1901; mown July 23, 1904.

TABLE XVIII.—*Amount of water in different fields that is probably available for the support of normal plant growth expressed as percentage of dry soil.*

Depth.	Field A.		Field B.		Field C.		Field D.		Field E,	Field F,	Field G.
	July 25, 1904.	Sept. 4, 1905.	July 25, 1904.	Sept. 4, 1905.	July 25, 1904.	Sept. 5, 1905.	July 25. 1904.	Sept. 5, 1905.	Sept. 5. 1905.	Sept. 9, 1905.	Sept. 9, 1905.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
First foot..	1.6	10.0	11.4	4.7	1.3	11.9	14.9	10.1	10.9	2.6	3.7
Second foot	.0	3.4	6.5	.0	3.2	4.1	10.2	3.6	3.8	.0	18.6
Third foot.	1.3	4.0	7.2	.1	2.1	1.6	10.6	2.6	5.1	.2	15.5
Fourth foot	2.2	6.2	7.4	.0	7.0	7.2	8.5	1.3	2.9	5.6	9.9
Fifth foot..	.5	5.7	9.7	5.5	6.4	7.4	4.1	6.4	5.5	6.7	8.1
Sixth foot.	2.0	6.4	7.1	8.1	5.5	10.1	8.1	8.1	7.3	7.6	7.8
Average.	1.8	6.0	8.2	3.1	4.2	7.0	9.4	5.3	5.8	3.8	10.6

In Table XII the total moisture content is given. The average percentage of total moisture in the first 6 feet of field F, which had produced a very heavy crop of straw and grain with a total rainfall of 13 inches, of which less than 0.8 inch had fallen during the last five weeks of its growth, was 21.9, while that in the fallow field B (1904), which had had two years in which to store moisture, was only 19.9. From the determination of total moisture shown, it would appear that field F, with its 21.9 per cent of water, was in better condition for seeding than field B, with its 19.9 per cent. In reality, however, field B was in excellent condition, while field F was practically exhausted of all moisture that could be used by a growing cereal. In Table XIII the fields are arranged in the order of their average moisture content, so as to show what relation this bears to their previous treatment. The sample of the sixth foot section from field D in 1904 was lost before the moisture was determined. To make results comparable, I have assumed in the tables that the moisture was the same as at the same depth in the same field in 1905. The stubble field D (1905) had the same percentage of total moisture as the fallow field B (1904) on the same farm. The field C, which had been continuously cropped with cereals since 1899, had almost as much water—19 per cent in 1905 and 18.5 per cent in 1904—as the fallow field B (1904). Yet fields B, C, and D were on the same farm and B is only a few hundred yards from C and D.

That the actual determination of total moisture gives less idea of the moisture conditions of different fields than a day laborer with a 6-foot auger could obtain is evident from Table XIV, which gives my field notes on the condition of the soil at the time the samples were secured. The terms " moist " and " very moist " need no comment. The samples adhering to the auger, but not moist, are called simply " dry." Those samples designated as " powder " resembled wood ashes and barely held to the auger when the latter was carefully removed from the bore. Those that formed " very dry powder " did not adhere to the auger and were removed only with great difficulty.

Table XV gives the hygroscopic coefficient of all the samples and Table XVI the free moisture of all. Table XVII shows the relation of the average free moisture of the first 6 feet to the treatment that the different fields had received. From this it is apparent that the percentage of free water in the fallows compared with that in stubble fields explains the difference in yield. The very low percentage of moisture in the rye-grass field is due to the practically complete exhaustion of available moisture from the fifth foot and the upper half of the sixth foot. The roots of the rye-grass reached to the middle of the sixth foot, while those of the wheat and oats grown on fallows evidently ended at depths between 4 and 5 feet. In Table XVI field C occupies an anomalous position, showing a higher average per cent of free moisture on September 5, 1905, than on July 25, 1904. Evidently crops on stubble under normal climatic conditions are not able to draw as much water from the lower 3 feet as those on fallows.

While the use of the hygroscopic coefficient in calculating the amount of free water enables us to form an idea of the difference in the amounts of available water held by different soils, it does not indicate the amount that is available in such form that the plant can continue a normal growth. It is probable that the water in the second to the fifth foot of the rye-grass field A (1904) and that in the second to the fourth foot of the oat field B in 1905, or in the first 3 feet of the wheat field F in 1905, would not have supported a growth of the cereals. It is probable that the normal growth ceases when the percentage of free moisture falls to from 4 to 8 per cent, according to the soil. Barley plants were grown for 6 weeks in a glass cylinder 10 inches deep filled with surface soil from Indian Head. At the end of this time water was withheld. When the barley plant died the soil at all depths below 2 inches contained 18 to 19 per cent of water. The hygroscopic coefficient was 12. Assuming that the minimum for soils of low hygroscopic coefficient is 4.5 per cent and for those of high hygroscopic coefficient is 6 per cent. Table XVIII has been prepared to show the amount of water available for normal growth. This is merely to suggest the desirability of trying to arrive at the minimum to which the moisture in a given soil may be reduced without impairing the health of the plant. It may differ much for different plants and at different stages in the growth of the same plant. As Hilgard and Loughridge have shown, it certainly differs much for different soils.

On the basis of the above determinations it seems safe to estimate that in the case of bowlder-clay soils as much as 500 tons of available water may be stored, while in clay soils of lacustral origin the amount may be much more. In neither case is the surface foot included, as the latter is liable to lose a large part of its water through surface evaporation at a time when the plants are too small to draw heavily upon its moisture. Further, the storage capacity of the soil below the reach of the roots of the plants in question is not included.

The soil of the Indian Head farm is much more pervious to water and has a smaller water capacity than the Moose Jaw soil. It will accordingly become saturated and allow water to pass into the soil below the fifth or sixth foot more readily than the latter. This would explain why as heavy crops have been obtained at Indian Head after corn, potatoes, and field roots as on fallow, these crops not using the whole of the ordinary seasonal rainfall and they being sown on soil fully stored with water. In view of the ordinary rainfall, the methods of cultivation, the system of cropping, and the nature of the subsoil, the large crop yields obtained at the experimental farm are to be considered as those from fields that were supplied with not only the rainfall of the crop season, but also with a large part of that of the preceding season. The stored water is much more valuable than an equal amount of rain falling during the crop season, not only because it contains a large part of the nitrates formed during the preceding summer and because it increases the supply of potash and phosphoric acid by enabling the roots to penetrate more deeply, but also because it is largely secure from surface evaporation.

The total available water of the crop season in the case of crops on fallow fields, to which, as I have mentioned, the yield of total dry matter of the crops at Indian Head has been roughly proportional, I calculated by adding 5 inches to the rainfall of the crop season.

Professor Shutt, of the Canadian experimental farm, has well shown the failure of experiments which take into consideration only the first 16 inches of soil to account for the extremely favorable influence of the fallow year. He determined the amount of water in two fields on the Indian Head experimental farm once a month from the beginning of the season to the end. His results are given in Table XIX.

TABLE XIX.—*Difference in the moisture content of cropped and of fallowed soil at Indian Head in 1900, to a depth of 16 inches.*

Date of sampling.	Rainfall from first of season to date of collection.	Water in Field S A (in fallow 1900, in crop 1899).				Water in field S B (in crop 1900, in fallow 1899).				Water per acre to a depth of 18 inches.		Excess of water in field in fallow, 1900.
		1 to 8 inches.		8 to 16 inches.		1 to 8 inches.		8 to 16 inches.				
		Per cent of moist soil.	Tons per acre.	Per cent of moist soil.	Tons per acre.	Per cent of moist soil.	Tons per acre.	Per cent of moist soil.	Tons per acre.	Field in fallow, 1900.	Field in crop, 1900.	
	Inches.									*Tons.*	*Tons.*	*Tons.*
May 8	0.27	22.03	264	21.32	277	25.87	386	25.55	325	541	711	−170
June 8	1.35	23.52	288	17.81	220	26.76	341	26.68	344	508	685	−177
July 8	3.20	24.39	302	22.38	293	23.62	289	18.35	213	595	502	93
August 8	5.64	24.78	308	19.28	242	25.05	312	19.07	223	550	535	15
September 8	8.47	24.16	298	21.65	280	21.28	252	20.50	244	578	496	82
October 8	12.28	25.26	316	22.39	293	27.60	356	22.07	268	609	624	15
November 8	12.38	25.79	325	22.83	300	26.14	330	23.35	288	625	618	7

The one field, S A, had been in crop in 1899 and was fallowed in 1900, while the other field, S B, had been in fallow in 1899 and bore a cereal crop in 1900. The kind of cereal is not stated in the publication referred to, but the dates of seeding, April 30, and of harvest, August 14, are given. The only crop having these dates was a 5-acre field of oats, which had been badly injured by wind, but produced 3,843 pounds of dry matter per acre. The seasons of 1899 and 1900 were in many respects unusually favorable for the experiments. The latter part of 1899 had been very dry, as may be seen from Table III, while from the opening of spring in 1900 until August 2 only 3.45 inches of rain fell, this being the driest crop season on record at Indian Head, with the exception of that of 1894. Wheat harvest began on August 2 and oat harvest on August 3. The moisture content in fields of cereals had probably been reduced to a very low point at the end of the summer of 1899, while the rainfall of May and June had furnished the fallow with a good supply of water. April and May of 1900 were very dry. The weather was unusually unfavorable for crops on stubble, as shown by Table VII. The full benefit of the fallow was shown in 1900. Nevertheless, the greatest difference shown by the samples taken to a depth of 16 inches was only 215 tons of water per acre, equivalent to less than 2 inches of rainfall. Heavy rains on August 2 (0.73 inch) and 6 (1.4 inches), with a shower (0.05 inch) on the 7th, raised the moisture content before the samples were taken on August 8. Similarly, the taking of samples in July had been preceded by rain, 0.01 inch on July 4, 0.95 inch on the 5th, and 0.42 inch on the 6th. Dry weather had prevailed before the samples were taken in May, June, and September. The crop of oats gave 3,843 pounds of dry matter per acre. This would have required 960 tons of water (equal to 8.5 inches of rain). It is very uncertain how much the rain of August 6 to 12 (2.25 inches) had affected the crop yield. A field of 2.5 acres of oats, which ripened on August 3, yielded 4,688 pounds of dry matter per acre. It also had been injured by winds. There were only 3.45 inches of rainfall available for the crop, the rain on the day before harvest not being counted. The water required for the crop, however, was 1,172 tons per acre (equal to 10 inches of rain). A 9-acre field of oats, protected from the winds by trees, which ripened on August 10, yielded 6,273 pounds of dry matter per acre, requiring 1,568 tons of water per acre (equal to 13.7 inches of rain). The dry matter of all the fields of wheat ripening from August 2 to 9 averaged 3,333 pounds per acre. A field of wheat, ripe on August 2, yielded 3,510 pounds of dry matter per acre, requiring 8.75 inches of rain, whereas the actual rainfall of the season was only 3.45 inches, and the decrease in moisture of 16 inches of soil amounted to only 167 tons per acre (equal to 1.5 inches of rain). This would leave 3.8 inches of rain unaccounted for, even assuming that the surface evaporation was as low as that in the experiments of King. The soils of fields S A and S B, judging from the moisture content when they were driest, were not very dissimilar to those of F and G (described previously), at least to a depth of 16 inches. The season of 1905 at Moose Jaw was similar to that of 1899 at Indian Head, being such as to produce the maximum difference at the time of harvest between fallow fields and fields in grain. Further, as the water content of a soil changes little during a cold, rainless winter, the moisture should have changed but little between September, 1899, and May, 1900. The difference between fields S A and S B to a depth of 16 inches on May 8 was 170 tons per acre, and on June 8, 177 tons per acre, while that between fields F and G, to a depth of 18 inches, on September 9, 1905, was about 175 tons of free water per acre. The latter fields, however, showed a further difference of 508 tons of free water per acre between the eighteenth and sixtieth inches, at the latter depth both being equally moist. It appears probable that if the moisture content of field S A, determined to a depth of 6 feet on November 8, 1900, had been compared with that of the same field on May 8, or with that of field S B on August 8, the difference would have been much larger even than that which I found at Indian Head in the case of the same fields in different years and of adjacent fields in the same year.

The results of my investigations in Saskatchewan and my conclusions drawn from these investigations may be briefly stated. Most of the generalizations and conclusions, I believe, will apply to dry farming in western Nebraska and western Kansas where deep and retentive soils are considered. The soil in Saskatchewan does not at any depth remain frozen throughout the summer. The moisture stored in the subsoil during the previous summer, and not the frost of the preceding winter, is the cause of the high yields of cereals. These high yields have in general been obtained from fields that were during the previous season in summer fallow or in cultivated crops, such as corn and potatoes. The roots of cereal and grass crops penetrate the subsoil to a depth of from 5 to 6 feet, even in seasons of unusually heavy and well-distributed rainfall. The total yield of dry matter of wheat, oats, and barley varies as the rainfall of the crop season, but shows a still closer relation to the total available moisture of the crop season. In the case of wheat the yield of grain from fallowed fields is largely independent of the rainfall of July and August, provided the rainfall of May and June has been abundant. Investigations of the fertility of the soils in which only the first 16 to 36 inches are considered do not furnish sufficient data upon which to base generalizations; in all such investigations the composition of the soil to a depth of 5 or 6 feet should be considered. The relative fertility of different areas seems to depend upon the nature of the subsoil rather than upon that of the surface soil, the latter in general being rich enough to produce very heavy crops when the moisture conditions are favorable.

Determinations of moisture, when these are not accompanied by determinations of the hygroscopic coefficient, are of comparatively little value in most cases. In semiarid regions roots go to the stored water, and the latter does not need to be elevated to the surface foot of soil. Comparatively little water is lost by direct evaporation from the subsoil below the first 12 inches. It is folly to begin dry-land demonstration experiments without having previously secured 6, or preferably 10, feet of good soil. In dry-land experiments tillage operations should be governed by actual determinations of the moisture conditions of the subsoil. The depth to which the determinations should be made depends upon the limit of the root penetration of the crop. After some experience the mere examination of the subsoil by hand and eye will give a fair idea of the moisture conditions. Accordingly, I expect to see all progressive dry-land farmers sooner or later provide themselves with an additional set of tools, namely, three soil augers, ranging in length from 3 to 9 feet.

CROP PRODUCTION UNDER HUMID AND DRY CONDITIONS.

By E. G. Montgomery, *Agronomist, Nebraska Agricultural Experiment Station, Lincoln, Nebr.*

It is very difficult to secure reliable statistics in regard to the cost of crop production even when the most careful data are kept. This is due to the great variability in climatic conditions over which we have no control that increase or decrease the crop more or less in spite of our efforts. By referring to Table IV, giving the average cost of producing corn on the farm of the Standard Cattle Company for a period of eleven years, it will be noted that the cost varied from 11 to 29 cents per bushel. This great variation in cost was probably not due to either better or poorer methods of cultivation, but mainly to climatic conditions. As we go farther west in Nebraska we find still greater variation in the cost of production. Corn has been produced as low as 7 or 8 cents a bushel in the West, and sometimes has cost 30 or 40 cents. Western farmers years ago began to discover that there seemed to be little correlation between the crop yields and the amount of labor they put on the crops. They sometimes procured very large crops with almost no labor, and at other times everything was a complete failure no matter how carefully tended. This uncertainty of a sure return for labor is always disastrous to any class of people, and in time they are apt to depend more upon Providence than upon their own efforts for a living.

Let us investigate a little the conditions in western Nebraska which have brought about this uncertainty and examine briefly the type of farming that has developed as a result. By examining Table I, which gives the average rainfall for a period of thirty years, you will notice first a great fluctuation in the precipitation.

TABLE I.—*Average rainfall in different sections of Nebraska, 1876–1906.*

Year.	South-west.	West.	North-west.
	Inches.	*Inches.*	*Inches.*
1876	9.89	10.69	16.25
1877	19.38	20.11	12.46
1878	25.54	13.76	28.92
1879	27.03	24.05	16.32
1880	21.07	17.64	13.18
1881	35.48	22.93	18.15

TABLE I.—*Average rainfall in different sections of Nebraska, 1876–1906*—Cont'd.

Year.	South-west.	West.	North-west.
	Inches.	*Inches.*	*Inches.*
1882	25.94	17.95	17.54
1883	31.17	30.01	24.36
1884	26.94	13.53	13.81
1885	33.28	22.03	18.81
1886	30.43	16.84	14.43
1887	24.60	18.98	21.64
1888	21.17	13.80	20.31
1889	28.11	16.46	18.75
1890	13.43	12.00	15.81
1891	33.32	23.75	24.73
1892	22.43	19.72	27.89
1893	15.67	10.28	14.38
1894	10.33	11.30	12.54
1895	20.14	11.18	15.28
1896	24.35	17.31	19.48
1897	24.94	19.52	19.10
1898	22.23	16.65	15.57
1899	16.76	13.42	16.25
1900	18.56	14.90	19.61
1901	20.34	16.70	22.53
1902	28.05	21.27	19.17
1903	25.50	14.36	19.88
1904	22.89	15.92	18.19
1905	33.30	24.81	25.52
1906	23,51	23.81	23.48
Mean	23.73	17.60	18.85

Upon two occasions the whole southwestern section has had 10 inches or less of rainfall, while it has also had over 33 inches four different years out of the last thirty. In the western section they have had only 10 to 14 inches of rainfall eight years out of thirty, while they have had as high as 30 inches one year and 22 or more seven years out of the thirty. The figures for the northwestern section are similar. There is much evidence to indicate that with about 22 inches of rainfall they are reasonably sure of a crop with almost any kind of farming in the western portion of the State. On that basis the southwestern section of the State would raise a crop about half of the time, while the western section would raise a crop seven years out of thirty, or about one crop in four years.

Perhaps a better idea of the variability of rainfall may be obtained by examining particular points, as it is not always fair to take the average rainfall for a large region in the West. Rainfall is very apt to be local, especially in western Kansas and Nebraska. This is brought out in Table II, where we have tabulated the rainfall for three different localities in western Nebraska—Culbertson in the southwestern part, Sidney and Kimball in the western part, and Fort Robinson in the northwestern part.

TABLE II.—*Rainfall at three points in western Nebraska, 1884 to 1905.*

Year.	Culbertson.	Sidney and Kimball.	Fort Robinson.
	Inches.	*Inches.*	*Inches.*
1884	....	....	13.9
1885	....	....	19.0
1886	....	7.7	11.0
1887	....	17.4	25.2
1888	....	10.9	17.5
1889	20.6	14.6	13.9
1890	13.9	12.1	11.7
1891	30.6	18.4	18.7
1892	23.0	21.4	32.3
1893	....	8.6	10.8
1894	6.8	....	14.4
1895	19.8	11.1	14.6
1896	18.4	....	12.6
1897	28.9	20.9	10.4
1898	19.7	18.0	14.1
1899	17.7	12.2	14.3
1900	15.4	14.9	19.6
1901	16.8	17.5	19.8
1902	23.8	17.3	19.5
1903	20.7	13.6	16.8
1904	20.0	13.2	13.9
1905	26.1	25.5	....
Average	20.0	15.3	16.49

Culbertson.—Average for sixteen years, 20.01 inches; five years, over 23 inches; eleven years, over 18 inches; three years, 15 inches or less.

Sidney and Kimball.—Average for eighteen years, 15.3 inches; three years, over 20 inches; five years, over 18 inches; four years, 11 inches or less.

Fort Robinson.—Average for twenty-two years, 16.49 inches; two years, over 25 inches; seven years, over 18 inches; four years, 11 inches or less.

At Fort Robinson, with an average rainfall of 16.49 inches, which is almost below the minimum for crop production, they have had over 25 inches for two years out of the past twenty-two, and over 18 inches seven years out of the twenty-two, while they have had 11 inches of rain or less four years. There is no exact correlation between rainfall and crop production in this region, as hot winds or insects may easily destroy the crop even with plenty of rainfall. However, we know that a number of very good crops have been raised in that region, as much as 30 bushels of wheat and 60 or 70 bushels of oats within the last few years, and there seems to be evidence that with 18 or 20 inches of rainfall in this region the farmers are reasonably sure of a good crop. On that basis we might assume that at Fort Robinson they have had seven crops in the last twenty-two years, a light crop a number of other years, and a few complete failures. At Sidney they have had sufficient rainfall for a crop three or four years out of the past eighteen and a number of failures, while at Culbertson it would seem that they have had sufficient rainfall for a crop probably half the time. Table III illustrates in a more graphic way the variability of rainfall in this region, both for the crop season and for the year.

TABLE III.—*Variability of rainfall at points in Nebraska, Minnesota, Iowa, and Missouri.*

Locality.	Crop season (April to August, inclusive).			For the year.	
	Normal rainfall.	Variability.		Normal rainfall.	Variability.
	Inches.	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*
Fort Robinson, Nebr	10.88	4.47	41	16.49	23
Kimball, Nebr	10.96	4.66	43	15.50	33
Culbertson, Nebr	14.37	6.86	48	20.70	21
Lincoln, Nebr			48	27.95	24
St. Paul, Minn					13
Davenport, Iowa					16
St. Louis, Mo					14

The variability of rainfall during the crop season is from 41 per cent to 48 per cent at the three points first mentioned, while it is 21 per cent to 33 per cent for the year. It will also be seen that the per cent of variability is 48 at Lincoln. However, the annual rainfall is 28 inches at Lincoln and 15½ inches at Kimball, and a variability of 40 per cent makes a greater difference where the normal rainfall is really below the minimum necessary for crop production than where the rainfall is considerably above the minimum. For comparison, the variability of rainfall at several other well-known points is also given. The great uncertainty of crop production in this region has resulted in a type of farming somewhat peculiar to the West and in some ways rather a practical adaptation to the conditions. The people of this region are not shiftless, but are both practical and optimistic and deserve some credit for their ability to adapt their methods of cultivation to a climate of this nature and be able to succeed as well as they do. The principle in most of the farming seems to be to put as little expense as possible into the farming of an acre of ground, on the theory that if rains come a good crop will be produced and if rains do not come nothing will be produced under any conditions. This enables them to farm more extensively and to cultivate the land at one-third to one-half as much expense as in eastern Nebraska; hence, if they secure a crop one-half or one-third of the time it is produced almost as cheaply as a crop in eastern Nebraska. Their cheaper cultivation is due partly to the fact that weeds are less troublesome and partly to the fact that, owing to the drier seasons, the soil is kept in good tilth much easier. However, this should not be too encouraging, as there are many disadvantages connected with securing a crop only once in two or three years even though it may be produced as cheaply as a crop every year. However, it is this question of comparative cost of production under different conditions and with different systems of farming that really tests the merits of the case. The western farmers are now practicing an extensive system of farming, but a good deal is being said about the use of an intensive system of most extreme type. Just how far we shall proceed toward the intensive system must be determined solely on the comparative cost of production between the extensive and intensive systems of farming under western conditions.

In regard to the present cost of producing crops in the more humid and in the drier portions of the State it is not easy to secure reliable statistics. Table IV shows that for a period of eleven years, from 1889 to 1899, inclusive, it cost the Standard Cattle Company, at Ames, Nebr., an average of 19 cents a bushel to produce corn on an annual area of about 2,000 acres.

TABLE IV.—*Cost of producing corn at Ames, in eastern Nebraska, 1889–1899.*

Year.	Total acreage.	Yield per acre.	Total cost.	Cost per acre.	Cost per bushel.
	Acres.	*Bushels.*			*Cents.*
1889	1,485	27.0	$4,867.42	$3.28	12.2
1890	1,485	22.5	8,924.79	6.01	26.7
1891	1,825	23.0	9,154.20	5.01	22.0
1892	1,825	28.0	9,499.97	5.20	18.5
1893	1.325	45.3	9,198.80	6.93	15.3
1894	1,792	22.8	11.950.83	6.66	29.1
1895	1,875	40.6	14.181.48	7.56	18.6
1896	2,462	68.6	19,888.70	8.08	11.7
1897	2,717	41.1	17,772.85	6.54	15.9
1898	3,431	31.5	21,575.89	6.32	20.1
1899	1,644	35.9	12,015.80	7.53	20.0
Average	1,987	35.1	12,639.80	6.28	19.1

The average cost per acre was $6.28. However, the annual cost per acre varied from $3.28 to $8.08, and it will be noticed that the cheapest corn was produced the year when it cost most per acre, and the next cheapest corn when it cost the least per acre. Since these data were taken, the rent of the land and the price of labor have advanced from 25 to 50 per cent, so that corn in the same region at present would probably cost 23 cents or 24 cents per bushel to produce.

A few years ago Mr. Coburn collected data from fifty-four counties in eastern Kansas on the cost of producing corn. He showed that the average cost of corn for the ten years previous was 20½ cents a bushel. However, the rent of the land and the cost of labor have also gone up in Kansas about the same as in Nebraska, so that, if data were collected now, they would probably show that corn in Kansas is costing 23 or 24 cents. In Table V I have attempted to compile a few data showing the average cost of production of crops in Kansas and Nebraska. The first part of the table is compiled from Mr. Coburn's reports for the years 1897 to 1906, inclusive. Nine counties were selected in northeastern Kansas and nine counties in northwestern Kansas.

TABLE V.—*Cost of producing corn in Kansas and Nebraska, 1897–1906, inclusive.*

AVERAGE IN KANSAS.

	Northeastern Kansas.		Northwestern Kansas.	
	Corn.	Winter wheat.	Corn.	Winter wheat.
Yield per acre, bushels	26.3	16.6	13.5	9.77
Value per acre	$8.92	$10.82	$4.52	$5.68
Value per bushel	$0.336	$0.649	$0.356	$0.573
Cost per acre[a]	$6.60	$7.35	$3.00	$4.35
Cost per bushel[a]	$0.25	$0.44	$0.22	$0.45

[a] Estimated.

AVERAGE IN NEBRASKA.

	Eastern Nebraska.		Western Nebraska.	
	Corn.	Winter wheat.	Corn.	Winter wheat.
Yield per acre, bushels	33	18	15	10
Cost per acre	$6.60	$7.35	$3.00	$4.35
Cost per bushel	$0.20	$0.40	$0.20	$0.43

AVERAGE FOR KANSAS AND NEBRASKA.

Cost per bushel	$0.225	$0.42	$0.21	$0.44

From these tables it will be seen that the average yield of corn in northeastern Kansas in ten years has been 26.3 bushels per acre, and for the nine counties in northwestern Kansas, 13.5 bushels, practically one-half as much. The average price per bushel in western Kansas has been about 2 cents more, and the average value per acre about one-half as much. I have made a careful estimate of the cost of producing corn in eastern and western Nebraska, and assuming that it costs about the same in Kansas I use this to get the average cost of production in eastern and western Kansas. My figure for producing corn in eastern Nebraska is $6.60, counting rent at $3 per acre; labor of a man, $1 per day; of man, team, and tools, $3 per day.

A few years ago Mr. Coburn made an estimate of $5.73 as the cost of production in eastern Kansas, but as rent of land and labor were cheaper it is certainly more than that to-day. In western Nebraska I have estimated the cost of production at about $3 per acre. This difference in cost is due largely to the fact that they list more and plow much less, that the rent of land is about $1.50 cheaper per acre, and that fewer cultivations are necessary to destroy the weeds. Large tools are also used, and the ground worked more rapidly. I believe that $3 per acre is a fair estimate. On this basis corn in eastern Kansas for the past ten years has cost 25 cents a bushel and corn in western Kansas 22 cents.

Winter wheat has averaged 15.6 bushels for eastern Kansas and 9.77 bushels for western Kansas, about three-fifths as much for the west as for the east. I have again used my Nebraska estimates for the cost of production of wheat in eastern and western Nebraska. According to this estimate wheat has cost 44 cents per bushel in eastern Kansas and 45 cents in western Kansas. In obtaining the yield per acre my source of statistics has not been as extensive for Nebraska as for Kansas, but I have made as close an estimate as possible from the data at hand. According to these I would place the cost of producing corn at 20 cents for eastern and western Nebraska and wheat at 40 cents for eastern Nebraska and 42 cents for western. I think there probably is no real difference in cost per bushel between Kansas and Nebraska, but I am using the best statistics I can secure.

If my figures are at all reliable they show that at present, at least for the period of the last ten years, corn and wheat have been produced about as cheaply per bushel in western Kansas and Nebraska as they have in the eastern part of those States. From this it would seem that at least until the rent of land increases they are doing fairly good farming in the western sections. It must not be concluded, however, that because they raise grain as cheaply by the bushel their farming is as profitable, because there are many disadvantages with raising crops only a part of the time as compared with raising crops every year. For comparison, I desired to obtain some data in regard to cost of production under more intensive farming in the western areas, but was unable to find such data. It is to be regretted that some such data are not at hand, for upon the cost of production will depend the development of the intensive system of farming.

It must be remembered that the merits of a system of farming are not determined by what some one can figure out ought to be made by it, or even by what some expert is able to accomplish. For example, anyone ought to be able to figure out with the stub end of a lead pencil that farmers in eastern Nebraska should raise corn at 15 cents per bushel, and a few farmers are doing this, but it does not prove that the average farmer has the ability to do this. In the same way, while some of the intensive systems of dry-land farming seem all right in theory, we can not judge of their merits until thoroughly tried in the hands of farmers. The value of the system depends on what the farmers as a class may be able to do with it. No matter how good the system may be in theory or in the hands of an expert, if it is too complicated or the principles are too difficult to grasp by the average farmer, the system must be considered impractical.

This emphasizes the importance of collecting accurate data, not only on the cost of producing farm crops under average methods of farm practice but under more intensive systems as well.

BLOWING SOILS.

By L. E. Hazen, *Assistant in Dry-Land Agriculture, Hays Substation, Hays, Kans.*

The long-continued droughts in the semiarid belt are no more of a proposition than the excessive winds. As a rule such crops as wheat, barley, rye, sorghum, cowpeas, and Kafir corn will withstand a drought of six weeks to two months fairly well if there is no wind. Alfalfa will grow on 11 per cent of water in the first 3 feet, retaining a rich green color; two hours of 40-mile wind will stop all growth and cause a yellow tinge to appear on the leaves with 18 to 20 per cent of water in the soil and an air temperature of not over 80° F.

There has been much written to explain how to establish a soil mulch, but so far there is little information as to how to keep it. A dust mulch will check evaporation, but the first stiff wind will blow the mulch away. Because this fact is overlooked land is being sold in western Kansas and eastern Colorado for $10 an acre which is really not worth $5. The clean-cultivated land at Hays blows very badly each spring, as the records show: land which is lightly tilled does not suffer much.

The following is the cultivation history of the worst-blown land on the reservation this spring:

In November, 1904, the land was plowed and harrowed; in March it was again harrowed and was planted to spring crops—wheat, oats, and barley. The part of the field west of the road was disked and harrowed in mid-April, plowed in July, and harrowed but not packed, as heavy rain beat it down; August 6 it was harrowed to break the crust and kill weeds; September 30, drilling winter wheat commenced.

In the records the following comments are noted:

March 1, 1905.—During the three days' high winds this whole field blowed badly and considerable wheat is covered because of the flying dirt particles having lodged behind sorghum stalks and in low places. Wheat plants appear rather sickly, though the part in the ground is alive and thrifty.

April 24, 1906.—The high wind of to-day did much damage to all spring crops that were above ground, and the barley and spring wheat east of the road were affected most because of the constant drifting of particles from the wheat fields on the west side of the road.

April 26 to 30.—Where wheat is killed the ground is listed to corn.

May 28 to 31.—Cultivated with a 6-disk cultivator. Weather is dry. Cultivation completed June 4.

June 8 to 18.—Second cultivation. A special weeder was used after to conserve moisture; completed weeding 20th.

June 27 to July 3.—Cultivated the third time.

July 25.—Used spiked plank.

July 27.—Rain stopped this work.

August 4.—Commenced using one-horse cultivator between rows to make mulch. Cultivation continued until crop matured.

March 8 to 10, 1907.—Stalks raked and burned and disking commenced.

February 18 to 20.—In another part of this flat the fall-plowed land was gone over with a disk drill having press wheels on to prevent blowing and drifting; wind has been blowing at the rate of 40 miles for a day or two and part of the land has drifted.

It was noted from time to time that rough-harrowed land or that gone over in an east and west direction with a drill did not blow much in a 40-mile wind, but that broken by a special harrow did blow some. To determine the real value of rough harrowing, five 2-foot-square plats were laid off side by side on the hill south of the evaporation tank and the plats were treated as follows: No. 1 was a check plat, its surface being entirely free from vegetation, but no cultivation was given. No. 2 was rough-harrowed east and west, but was not stirred enough to make the dirt fine. No. 3 was also rough-harrowed, but the cultivation was so frequent that it had a very fine mulch. No. 4 had a broken crust of the same quality as No. 2, but was laid smooth instead of in ridges. No. 5 had a very fine, level, mulch surface.

In a 30-mile wind no blowing of any consequence took place, although plat No. 5 showed signs of losing dust; in a 35-mile wind Nos. 4 and 5 both blew some. In a 40-mile wind Nos. 3, 4, and 5 blew, and the mulch from No. 5 had to be reestablished. No difference in rate of blowing could be detected between Nos. 4 and 5 until the wind dropped to 30 or 35 miles, when No. 5 alone lost dirt. In a 50-mile wind No. 2 showed signs of blowing, as did the check plat; in a 57-mile wind all four cultivated surfaces blew away, but the check plat blew very little. The conclusion arrived at is that rough harrowing has no great advantage in a high wind.

The Department of Horticulture has a small timber strip which surpasses anything for blowing the writer ever saw. It runs north and south along the fence next to the highway. This field grew barley in 1904, and about the middle of September it was plowed and harrowed. A number of lister rows were opened, tree seeds being dropped and covered with a cultivator. The field was again cultivated in April, and then was kept continually loose with hoe, disk, cultivator, a tooth and slicing harrow, and throughout the season had a heavy dust mulch. The dust blew from this in clouds and drifted so thickly in the yard west of the boarding house as to kill weeds and grass in places.

An orchard plowed and harrowed this spring, then planted and intertilled, has not suffered from blowing as yet. The main tillage is east and west. This field was a big weed patch last year.

Trees do not start readily at Hays, but cottonwood and honey locust do fairly well, and where trees protect the south side of a field there is little blowing until a point is reached several rods from the protecting belt. Frequent timber belts running east and west, plenty of sod-forming crops, and care not to leave a smooth, fine-grained surface seem at present to be the best checks to this trouble.

PLANT BREEDING IN CONJUNCTION WITH DRY-LAND AGRICULTURE.

By L. R. Waldron, *Superintendent Agricultural Substation, Dickinson, N. Dak.*

While the variety testing, plant selection, and plant breeding carried on at the various experiment stations connected with the semiarid belt can not fail to be of much benefit to our cooperative work, yet the ground may not be entirely covered and valuable work may be undertaken at the substations in immediate connection with the different cooperative projects. Any work of this character must be undertaken seriously, be well planned in advance, and funds must be set aside to carry it out. Obviously the work should be of as simple a nature as is consistent with the results to be obtained. Simple and well-tried methods applied along new lines may produce as satisfactory results as though more modern theories were used with a less sure hand.

In the past plant breeding, or perhaps more properly plant selection, has been devoted mainly to an increase of yield, an increase of rust resistance, of drought resistance, of hardiness, of milling quality, etc., and while these qualities are desirable and even necessary in our work, it may be that there are other qualities of equal value to be developed in grains which are to become preeminently suitable for our dry areas. Or may it not be possible that some of the qualities mentioned are really complexes which by appropriate methods may be analyzed into simpler elements? The terms vigor and hardiness may mean much or little, depending on the user's standpoint. We are learning that the term " drought resistance " has an increasingly wider meaning, subjectively; and until we know the methods by which the plant may overcome lack of moisture we may hope to make but little progress by selecting along this line.

What are some of the difficulties against which cereals have to contend in the area which interests us? Surely one of the difficulties, though not the chief, is the cold soil which the spring-sown grains find ready to receive them. At Dickinson this season some grain scattered from the thrasher germinated in March and maintained a successful growth until the first of June, when it was pastured, being far in advance of grain sown in early April, which did not appear above ground until the first week of May. This great difference was evidently due almost wholly to the warmer substratum secured to the early germinating grain. Now, while it may be difficult to move the mountain Mahometward by warming the soil, it may be possible to dislodge Mahomet by modifying our grain. At any rate the idea is worth thinking about, and perhaps acting upon.

In a variety of grain is it not possible that there are some kernels which will start at a lower temperature than other kernels? From the writer's observation upon grain sprouted in a germinator at a rather low temperature it seems very probable that this is so. Proceeding on this assumption, it would seem but a simple matter to run the germinator at a temperature just below the degree necessary to cause germination for that particular variety, and from several thousand grains there may be one hundred which start at this lower temperature. These could be transplanted to the open ground and selection could then be made for yield and other qualities. The next year the selected grains could be put through the same or a more exacting germinator test and the work continued as long as desired.

From the writer's observation on the germination of certain weed seeds, it seems reasonable to suppose that the germinating temperature point varies widely with the seed of any one species and that those which germinate at the lower temperature are more frostproof than the remainder. If this should be found to be true of grains, we would be developing not only a strain that germinates at a low temperature, but one that is frost resistant also—a valuable desideratum.

We need not only a grain having the above germinating characters, but one that will germinate with a minimum amount of moisture. The ground at planting time in the semiarid regions is apt to contain less than the optimum water content for germination. A grain that would accommodate itself to the drier conditions would aid the farmer in making good in his struggle for maintenance. It would seem feasible to fit up a germinator having the moisture content under control. In such a germinator, having the moisture content just below the minimum for germination, there could be selected grains or seedlings requiring the minimum amount of moisture. Such seedlings could then be planted out.

These ideas could be carried out in a limited manner by purely out-of-door methods, but the work would be under better control and results would be attained more rapidly if the most essential portion of the work were carried on inside. Perhaps a method more suitable than that of the seed germinator would be that of a small glasshouse the temperature of which could be controlled. In such a place the plants could be started at the minimum temperature and later transplanted. In other beds, with the moisture content kept at certain percentages, seeds could be sown and the desired seedlings could be transplanted and treated as seemed best. In carrying out the above suggestions the idea of using the various methods in combination readily comes to mind.

While the difficulties attending plant selection carried on along the lines indicated are of some importance, yet it is believed that they are not insuperable, even to the substations. Furthermore, the beneficial results accruing should prove of much importance, not only as an end in themselves, but for the light that would be thrown upon other problems now scarcely guessed at.

RATE OF SOWING DURUM WHEAT.

By L. R. Waldron, *Superintendent, Agricultural Substation, Dickinson, N. Dak.*[a]

The statement is often made, by scientists as well as by farmers, that in sowing durum wheats the drill should be set to sow more than if sowing Fife or Bluestem wheats. This statement seems to be based on three assumptions: (1) That the grains, being larger, feed more slowly through the drill; (2) that the grains, being larger, a greater volume per acre is needed in order that as many grains per acre be sown as of the common wheats; (3) that as the durums stool less, they need to be sown more thickly in order that as many heads per given area may be produced as in the case of the common wheats. These postulates overlap somewhat and can not all be used in the same argument.

Recently the author has made a little study with a view to testing the soundness of the practices derived from the above conclusions and also of the conclusions themselves. Two varieties of wheat were selected—Kubanka and Rysting's Fife. The Kubanka weighed 63 pounds and the Fife 61 pounds to the bushel. Ten grams of each variety were weighed, and in the durum sample there were found 247 grains, as against 304 grains in the Fife sample. This is an excess of 23 per cent of the Fife grains over durum for a given weight and only a fraction less than 23 per cent for a given volume.

Equal quantities—about 5 pounds each—of the two varieties were weighed out and each sample was placed in one half of a 6-foot drill having but one feed. The drill was set to sow 6 pecks of common wheat. Enough revolutions of the shaft were made to sow one-twentieth of an acre. The wheat that passed through the hose was collected and weighed. It was found that of the Kubanka there were 1,088 grams and of the Fife 1,079 grams that had passed through the drill, a difference of less than 1 per cent, although it was found that the durum grains were 123 per cent the size of the Fife grains. It thus appears that under the conditions given, the two wheats feed at about the same rate. If this holds generally, the first assumption is unfounded.

The second statement is self-evidently true; but is it necessary that more grains, or even as many grains, of the durum be sown per acre as of the Fife in order to produce the best results? It is true that the durums stool less, but is it necessary that they stool so much as the Fifes or Bluestems to produce as much per stool? Are there no other factors entering that tend to offset the deficiency in stooling? In an attempt to answer this question in part, weighings may be given of some stools of these two varieties. They were grown in nursery plats under similar conditions, except that the Fife wheat was sown twelve days later than the durum. Six durum stools and seven Fife stools were selected on the basis of general quality—primarily yield as expressed by stooling. Of the durum, the six stools averaged 4.3 heads to the stool. The shelled grain averaged 10.11 grams per stool. The seven best stools of the Fife averaged 6.8 heads per stool and the shelled grain averaged 6.62 grams per stool. The shelled grain per durum stool thus shows itself to be 52 per cent greater than similar grain from the Fife stools. The durum grain yielded on an average 2.35 grams per head, while the Fife wheat yielded but 0.97 gram per head, an excess of over 140 per cent in favor of the durum. To put the matter more concretely, in order to produce a crop of 30 bushels per acre it would require a stand, according to the figures given, of 16 stools of the Kubanka wheat per square yard, as against 25 stools of the Rysting's Fife. If we were to do any *a priori* reasoning from these figures, the conclusion certainly would not be that the durum wheat needs to be sown the more thickly—rather the reverse. While the data given do not aid us materially in field practice, they serve to brush away certain deductive conclusions and preconceived notions that might prevent a good understanding of the subject. There may be reasons for thicker sowing of the durum, but it is scarcely possible that they lie along the lines indicated at the beginning of this paper.

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[a] Mr. Oliver J. Grace aided in securing some of the data for this paper.

FRUIT GROWING ON THE PLAINS.

By J. E. Payne, *Superintendent, Agricultural Substation, Akron, Colo.*

One who has been accustomed to going to the orchard or fruit garden and eating fruit fresh from the trees can hardly imagine that it would be possible to live and raise a family without using fruit of some kind as an article of diet. When fruit is shipped a long distance it is never as good as the fruit which one would select from his own orchard, while the prices which must be paid for the inferior article which the stores occasionally have for sale are prohibitive to the average settler who files on a claim and attempts to eke out an existence for himself and family. So if the children of the Plains country are to have as much fruit as they should have it must be raised at home.

The Plains country is likely to be settled by people who can not get a foothold where land is high priced. They must learn to farm under conditions as they exist. They must find drought-resistant crops for extensive use, and must learn to create suitable conditions for the production of their favorite fruits and vegetables which are not drought resistant. In other words, they must adapt themselves to conditions and learn to create environments suitable for some plants which can not be grown in the community under natural conditions or ordinary methods of culture.

The agriculturists and agronomists are all working and studying to find or produce drought-resistant grains, grasses, and fruits. But I contend that these would avail but little if we could not find “drought-resistant” settlers who are willing to live in the country and demonstrate their value.

I have found that the quality of drought resistance is not confined to the settlers from any State or nation. It seems to be an individual trait instead of a quality of race or country. The man who can adapt himself to the conditions and do the right work at the proper time succeeds in maintaining himself, and those who do not do this fail.

It is argued and has been argued that it does not pay to try to grow fruit and vegetables on the Plains because they can be bought cheaper than they can be raised. But I have noticed that those who talk that way have a very small variety of vegetables on their tables and that they seldom eat fruit of any kind, except the cheapest kind of dried fruit, unless perchance the man happens to be owner of a large ranch from which a few hundred " feeders " are annually sold. Even the wealthiest ranchmen fail to find good fruit and vegetables on the market at all times, and they can supply themselves only by maintaining an orchard and garden for the production of their own supplies of this kind.

Fruit growing, gardening, and forestry as practiced by the ordinary farmer or ranchman are business propositions which it is impossible to demonstrate will pay in dollars and cents for all the work put into them. But as a factor in home building it certainly is easily shown that a good supply of fresh vegetables and fruits is worth all it costs in labor and money, especially when one must either produce his own supply or go without.

Farming as practiced by the majority of men owning the land which they use is a home-building proposition instead of a business venture. Some men I have known whose annual production would not average $500 cash market value per year have lived on the Plains and raised large families. As wages for a man and his wife and children, all working hard, this does not seem like a business proposition. But the same man, if placed in some factory, would have to earn all the income, and he would not earn any more than the family earns on the drought-stricken prairie. If the father was employed in a factory the children would miss the sturdy training in thrift and industry that helping with the stock and doing farm work give. So, while at first the settler may appear to be playing a losing game, when we consider ultimate aims he has probably done more for his family and for society at large by raising a few honest, industrious men and women, who will also be " drought resistant," than he could do in any other way, and they will be able to give efficient aid in conquering the remainder of the American desert.

Introduced trees and shrubs which have been tested have often given results not on account of drought-resistant qualities but because their fruit grew and ripened during the part of the year when humid conditions existed.

Cherries, plums, and gooseberries have usually produced well. Only standard varieties of these have been tested by the writer, and it is his belief that they have succeeded because they make their growth of fruit before July 1, or before the usual time of drought. The Russian mulberry can also be depended upon to produce considerable fruit, which gives much pleasure to birds and children, and several varieties produced fruit at Cheyenne Wells. The sand cherry and the wild black currant are found native in many parts of the Plains area. These also grow their fruit mainly during the humid parts of the year. Apples have not been successfully grown without irrigation, except during periods of excessive rainfall. Apple trees have been grown in many places on the Plains by careful tillage, but nearly every year there is a time when the fruit is injured by drought. If the owner is prepared to give the trees a good irrigation at these critical times, they will produce good fruit. Otherwise much of the fruit falls and that which remains does not ripen properly, but withers and never has a good flavor.

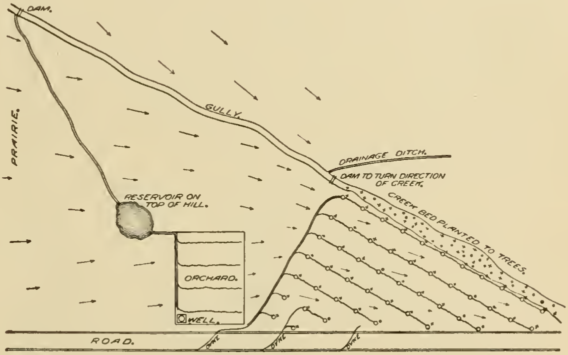
DAM.
GULLY
PRAIRIE.
DRAINAGE DITCH.
DAM TO TURN DIRECTION OF CREEK.
CREEK BED PLANTED TO TREES.
RESERVOIR ON TOP OF HILL.
ORCHARD.
WELL.
ROAD.
DYKE
DYKE
DYKE

FIG. 1.—Diagram of James Howell's orchard, Flagler, Colo.

As water is necessary for trees or gardens, these should be located where it will be possible to give the trees extra water in some way and also guard against an accumulation of excess water about their roots in times of heavy rainfall. The ideal location for an orchard is on a slope adjoining permanent pasture land, where the storm water may be carried to ditches made just above the rows of trees and distributed automatically during the storm, each tree to have a hole just above it on the slope, which will be filled from the prairie flood water. This method is shown in the map of James Howell's orchard, which is situated near Flagler, Colo. (See fig. 1.) The mistake of not providing for drainage is shown in the same orchard. The trees planted in the creek bed below the dam were much damaged by extra water during a season of excessive rainfall. During dry years they did well, but when a series of years having abnormal rainfall came many trees planted in the old creek bed died.

Having chosen the location, the next thing to consider is the preparation of the land. Two extreme methods have been practiced, both with fair success. One is merely to dig holes for the trees and set them in the sod; the other is to plow the land several times during one year, each time a little deeper, and again in the spring just before planting. At this last plowing the tract is plowed in narrow lands, so that each row of trees will be planted in a dead furrow. Holes are dug and the trees set carefully with roots naturally spread. The top soil should be thrown in first and carefully packed. Trees should not be set when the ground is wet. The trees should be set and covered a little deeper than they were in the nursery row. The holes should be deep enough to be left with about 6 inches unfilled. This, with the furrow in which the holes were dug, will make a reservoir for holding storm water until it can sink into the ground. The trees planted should be trimmed so as to balance the root system and the top. Cut off all bruised roots and limbs and leave the limbs which are in position to make each tree well balanced. Pruning in after years will be likely confined to cutting out interfering branches. Each year more wood will be cut out, until after a few years a wagon load of brush will be cut from an acre of apple trees each year. Pruning should be done just before the growth starts in the spring, so that the wounds will quickly heal before they are exposed to dry, cold winds.

The orchard should be cultivated carefully, so as to keep the weeds down and preserve a soil mulch. The disk harrow is probably the best tool we have for maintaining a deep soil mulch. The smoothing harrow used with teeth set slanting forward is good for maintaining a moderately deep mulch. I have always begun cultivation early in March and stopped by August 15. Some years the orchard was not cultivated after July 31. Frequency of cultivation depended upon rainfall. The tool used for any cultivation also depended upon the condition of the ground. I never tried a cover crop, as I had the care of one orchard only eight years, and it grew well under clean culture and was not large enough to make any tests which would have been of any value.

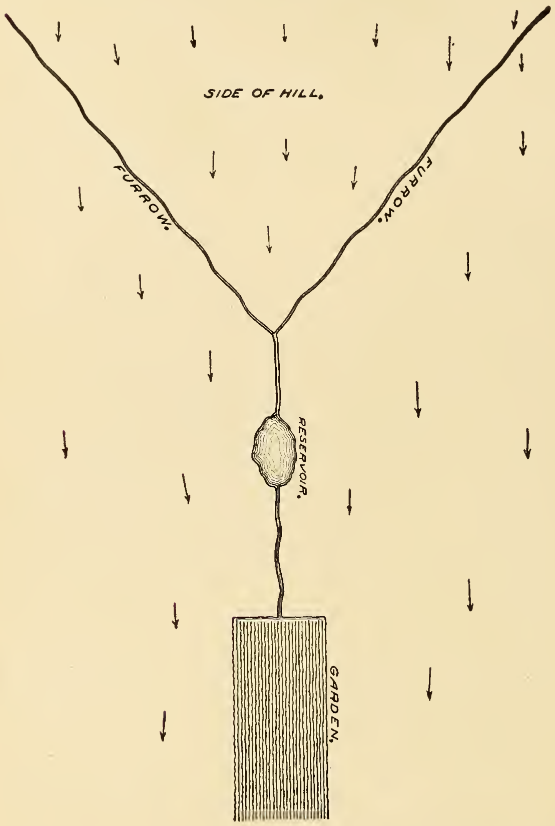

FIG. 2.—Diagram showing simple method of utilizing storm waters.

The fruit garden should not be extensive, but should include enough trees of each kind to furnish a succession during the summer and an abundant supply for winter use. It should be surrounded by a windbreak of hardy trees. I would now plant three rows of hardy trees 8 feet apart each way if I were planning a garden. I would use Russian mulberry, black locust, and wild Russian olive for making the shelter belt. The black locust and wild olive are ornamental trees, and the Russian mulberry bears fruit which is quite acceptable to the bird friends and children.

The work done in testing fruit trees has been pioneer work only. It has been demonstrated that fruit trees will grow in the Plains country if cared for properly. Variety tests should follow. We have produced good crops of Weaver, Minor, and Wolf plums; also good crops of Early Richmond, Early May, and English Morello cherries. The Downing gooseberry has done well. Apples of standard sorts, as Ben Davis, Missouri Pippin, Winesap, and Duchess of Oldenburg have all thrived and have borne a few good crops. Peaches have often winterkilled, so if any of them are raised hardy sorts must be imported or the trees must be covered during the winter. Apricots make beautiful trees, but they nearly always blossom too soon in the spring to produce a crop of fruit. Standard grape varieties, such as Concord and Delaware, produce vegetative growth, but seldom fruit.

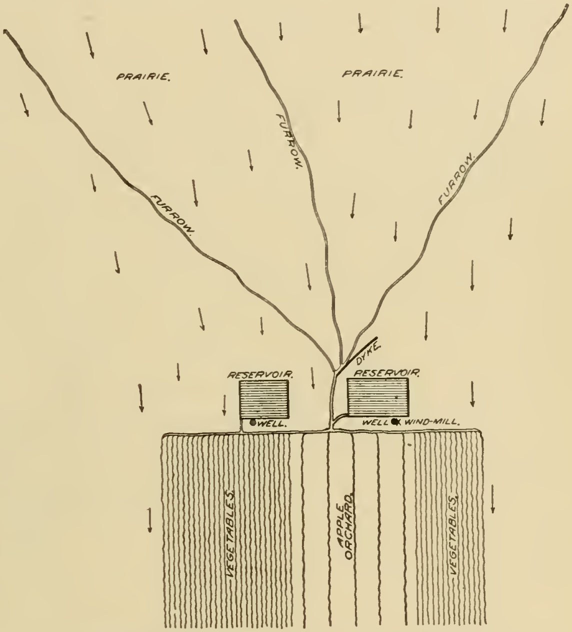

FIG. 3.—Diagram showing combination of windmill irrigation and utilization of storm waters near Akron, Colo.

After protection from the storms, the most important consideration in the production of fruit is a certain water supply in time of need. Some try to store this in the soil by cultivation, and when storm water can be drained from other land onto the fruit garden this method is a success. But during dry years trees suffer if they get only the water that can be saved from the rain which falls upon the space occupied by the orchard.

Another method is by irrigating from wells. Some use a combination of these two methods.

In the accompanying illustrations are shown some methods of getting extra water for the fruit garden. Figure 2 shows a simple method of catching the water from a hillside and storing it in a buffalo wallow situated above the garden. This reservoir is fed by a deep-trodden cattle path. It holds water for several days and this is put upon the garden where it is most needed.

Figure 1 shows a more complicated system involving the same general plan and used in combination with a well, so that if the storm water does not come at the right time the trees may be watered from the well. This garden is located near Flagler, Colo. The reservoir on the hill is fed from the prairie by throwing a dam across the head of an arroyo or gully and making a ditch from above the dam to the reservoir. The same arroyo is dammed lower down and turned out of its course, leaving the old channel dry but subirrigated from the pond above the dam. Trees were planted in the old channel, but the wet years of 1904 and 1905 caused them to be much damaged by too much water standing about their roots and many of them died. During the dry years these trees did well. The trees planted upon the slope get the storm water from the higher land and the holes above the trees on the slope are often filled. This extra water, combined with good cultivation, has kept the trees on the slope in good condition and able to bear fruit every year, although the crop is sometimes destroyed by hail. This fruit garden was set out about fifteen years ago and drought has caused no failures there.

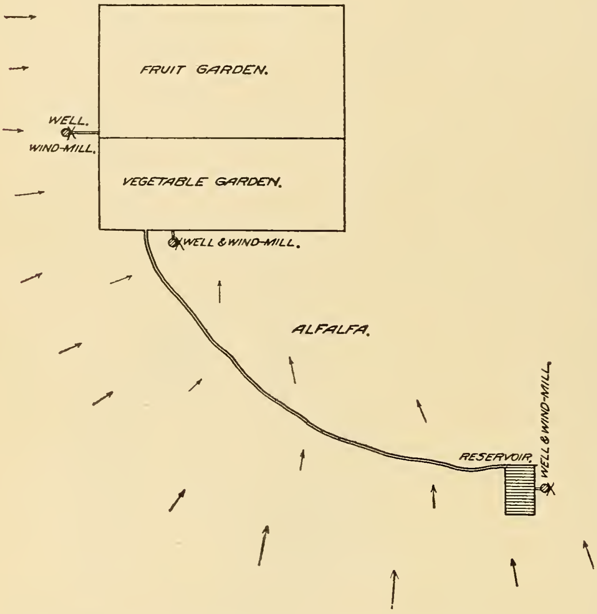

FIG. 4.—Diagram showing windmill irrigation as practiced by John Rose, Seibert, Colo.

Figure 3 shows another combination of the use of storm water, with windmill irrigation. This is a commercial fruit and vegetable garden. It is located near Akron, Colo., and the owner has supplied the community with vegetables and small fruit for several years. The storm water is used to water the trees and large crops, while the water from the wells is stored and used for watering vegetables. This garden has furnished an income of about $800 a year, besides the ice crop from the reservoir, which often amounts to $500 a year.

Figure 4 shows a type of windmill irrigation plant of which there are many on the Plains. The one chosen belongs to a pioneer in this line, Mr. John Rose, who is located near Seibert, Colo. Mr. Rose began with one well and no mill. Later a mill was obtained, but blew down, and until it was put up again, several weeks later, Mrs. Rose pumped water by hand five hours every day in order to save her strawberries and trees. This garden was only a few square rods in extent at first, but it was extended as experience dictated until now three wells water about three acres. Mrs. Rose says that the little fruit garden enabled the family to live when they would have been compelled to leave if their garden had not been a success. Many of their neighbors sneered at the "little patch" at first, but now, after eighteen years of demonstration, every settler within 10 miles of Mr. Rose has a small fruit garden, and they have nearly all obtained strawberry plants from that pioneer fruit farmer.

There is no doubt that every man can have a fruit garden if he is willing to make sacrifices to start it and care for it; but he must remember to make conditions to suit the plants, instead of trying to change the plants to drought-resistant varieties.

OKLAHOMA ROTATIONS AND THEIR RELATION TO SOIL-CULTURE WORK.

By L. A. Moorhouse, *Agronomist, Oklahoma Agricultural Experiment Station, Stillwater, Okla.*

Rotation of crops in agriculture and horticulture has been defined as the system or practice of growing a recurring series of different annual crops upon the same piece of land. The system is based on the fact that various crops not only require but absorb different quantities of the mineral constituents of the soil; hence, if one crop is grown continuously upon the same section of land for a period of years and one of the essential elements is drawn upon to an excessive degree, it is evident that unless the supply of this constituent is present in unlimited quantities, the plant food elements will be thrown out of balance and low crop yields will result. Sir Henry Gilbert, in presenting a review of the rotation experiments at the Rothamsted station, gives us the following definition:

> If I had to define the practice of rotation of crops as followed in our own country (England)—indeed, over large portions of Europe—in the fewest possible words, I should say that it consists in the alternation of root crops and of leguminous crops with cereals. In the United States, however, it is a gramineous crop (maize) which largely takes the place of the root crops in Europe.

The same writer also makes the following observations:

> The cereals constituting such a very important element of human food, it was natural that they should be grown almost continuously so long as the land would yield remunerative crops. Hence, the history of agriculture, not only in our own country but in others where these crops were of high relative value, shows that it very generally came to be the custom to grow them for a number of years in succession and then to have recourse to bare fallow, or in some cases to abandon the land to the growth of rough and weedy herbage, affording scanty food for domestic animals.

This is precisely the history of agriculture in this country. First, the one-crop system constitutes the sole arrangement for the farm; then a reduction in yield necessitates some modification, and we note that an abandoned farm is the final outcome. History must not repeat itself in the West. With all our modern ideas in the realm of chemistry, with new light in the field of biology, and with a mass of experimental data from the physical laboratory, where the soil is carefully studied, the problems which are confronting the agriculturist of the West should not go unsolved. It is my belief that we are coming to a plane where more substantial experimental work can be planned and carried into effect, but this fact should not lead us to relax our efforts or to conclude that the goal has been reached, for it appears to me that we are merely commencing to grasp first principles.

Several reasons may be advanced in favor of a well-planned rotation. In the first place, the adoption of such a system will enable the husbandman to distribute the farm labor throughout the greater part of the year; thus men who were formerly engaged for short periods will be given continuous employment. Again, a variety of crops, marketed at different periods of the year, gives a steady and regular income to the farmer, and, as a matter of fact, he will be able to manipulate his affairs with a smaller capital. Success in commercial life depends to a great extent on the business management, and this is also true in regard to agricultural pursuits. A good rotation affords an opportunity for making regular applications of farm manure on the respective areas; hence, the fertility of the soil will not deteriorate as rapidly as under the one-crop system, where manure is added sparingly; moreover, clean-culture crops can alternate with uncultivated crops and weeds may be held in check quite effectively. These and other reasons which might be given are decidedly in favor of a definite system in the order of cropping.

One of the first questions which comes to us in making suggestions for the farmers of the West is this: "What factors should be observed in planning a rotation?" This question can not be answered for us from the standpoint of the eastern farmer, although the latter might receive instruction by observing western methods, and we can undoubtedly profit by investigating his plans. It is possible that some of our failures in the semiarid region have been due largely to a strict adherence to some local ideas which have been imbibed under entirely different surroundings. The newcomer must learn to adapt himself to new conditions, and in order to do this successfully a study of the past history of this great area will be imperative. The conservation of soil moisture is an important item; thus, if maximum returns are to be secured, this factor must be reckoned with in the arrangement of our rotation.

In discussing these factors it will be necessary for me to confine my attention to data which have been collected during the past ten years at the Oklahoma Agricultural Experiment Station. The rainfall for this point is much higher than the rainfall which is reported for western parts of the territory; however, if any general deductions can be made in a study of our records for this county, a few of these lessons may be applicable under western conditions.

In the first place, let us consider the precipitation throughout a period of years, and perchance we may determine the relation between the rainfall and our crop systems. Our records are complete for the years 1896 to 1906, inclusive; and the monthly distribution for this period is given for two five-year periods. The average for the first five years—1896–1900—is given in Table I, while the average for the second period—1901–1905—is given in Table II. The latter table also contains a ten-year average. The report blanks from which these figures were taken were apparently incomplete for the years 1893 to 1895, inclusive, consequently it would hardly be correct to make any comment for this period.

Table I.—*Precipitation at the Oklahoma Agricultural Experiment Station for 1896 to 1900, inclusive.*

Month.	1896.	1897.	1898.	1899.	1900.	Average, 5 years.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
January	0.55	0.76	3.53	0.48	0.23	1.11
February	19	1.51	3.00	.47	.79	1.19
March	1 21	3.51	2.75	1.03	.51	1.80
April	.94	6.36	.58	4.97	4.43	3.46
May	5.93	4.77	8.56	5.61	3.71	5.72
June	7.26	4.13	4.72	3.64	3.28	4.61
July	5.85	2.63	6.35	4.54	2.69	4.41
August	1.64	4.51	2.86	2.57	1.39	2.59
September	2.54	71	2.72	.88	9.22	3.21
October	2.88	97	4.19	5.15	2.87	3.21
November	1.56	.80	.68	1.93	.65	1.12
December	.85	.87	2.68	1.60	.21	1.24
Year	31.40	31.53	42.62	32.87	29.98	33.68

The snowfall for this five-year period was not excessive, and yet there was sufficient to furnish at times a fair supply of moisture for the soil. It should be noted that almost the entire quantity of water falling in the form of snow eventually passes into the soil, because the time required to melt the snow generally exceeds one or two days, and if the material is not carried from the field by high winds some addition is made to the capillary water of the surface and subsurface area. The distribution for the period was as follows: January, 1896, 0.08 inch; January, 1897, 0.05 inch; December, 1897, 0.49 inch; December, 1898, 1.25 inches; January, 1899, 2.5 inches; February, 1899, 0.5 inch; March, 1899, 1.9 inches; December, 1899, 4.5 inches; January, 1900, 0.12 inch; February, 1900, 1.2 inches. The maximum snowfall for this period occurred in December, 1899. It should be observed that this precipitation was timely, inasmuch as the rainfall for the three subsequent months did not exceed 1.52 inches. In making a study of the average precipitation for this five-year period two or three facts should be noted. First, our maximum rainfall occurs during the month of May, while the minimum point is reached during the month of January. The average rainfall for November, December, January, and February is comparatively low.

TABLE II.—*Precipitation at the Oklahoma Agricultural Experiment Station for 1901 to 1905, inclusive.*

Month.	1901.	1902.	1903.	1904.	1905.	5-year average.	10-year average.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
January	0.62	0.13	0.25	1.03	1.79	0.76	0.94
February	.59	.17	2.19	.07	1.17	.84	1.02
March	2.95	5.03	3.66	.15	5.42	3.44	2.62
April	1.29	1.92	2.97	.80	2.80	1.96	2.71
May	4.70	10.86	9.27	7.28	4.86	7.39	6.55
June	.79	2.19	.73	6.54	3.76	2.80	3.71
July	1.48	2.85	3.47	5.18	3.19	3.23	3.82
August	1.95	2.17	2.48	7.42	8.15	4.43	3.51
September	1.11	4.64	3.01	1.66	2.38	2.56	2.89
October	2.11	.92	3.52	.13	2.88	1.91	2.56
November	.95	7.78	.55	.21	1.57	2.21	1.67
December	.90	1.63	.48	2.52	.62	1.23	1.24
Year	19.44	40.29	32.58	32.99	38.59	32.78	33.23

The snowfall for this five-year period stands as follows: February, 1901, 1.4 inches; December, 1901, 2 inches; January, 1902, 0.5 inch; December, 1902, 0.9 inch; February, 1903, 1.5 inches; February, 1904, 0.25 inch; November, 1904, 0.05 inch; December, 1904, 0.75 inch; February, 1905, 1.12 inches.

The annual average precipitation for the first five-year period was 33.9 inches, as compared with 32.78 inches for the second period, giving an average for the ten-year period of 33.23 inches. The average monthly precipitation for the years 1896–1900 reaches a maximum point during the month of May, while the lowest rainfall occurred in January. In our second table, which includes the years 1901–1905, the month of May shows the maximum precipitation for the five years, and the lowest point is reached during the same month as in the previous five-year period. The general results in the second period are practically the same as in the first. During the past two years there has been a marked increase in the rainfall for August, and this, with the rainfall for 1906, will have a tendency to raise the average for this part of the season. In general, our average precipitation runs low for the months of November, December, January, and February; then there is a gradual rise to the maximum point in the month of May, and subsequently the averages gradually decline until the end of October.

After making a careful study of these tables I have been led to reach the conclusion that there is a direct relation between the precipitation for this section and the recommendations which have been submitted by our station workers for the guidance of the farmers of the territory. For instance, the fall seeding of alfalfa has usually given more satisfactory results than spring seeding. As a matter of fact, crab-grass (*Panicum sanguinale*) gives less trouble in the fall-sown than in the spring-sown alfalfa, but there is still another reason for the existing preference, and this is found in the fact that the heavy rainfall of the spring months has a decided tendency to wash our fields; hence, many of the young alfalfa plants are destroyed. If the field is plowed early in July and is given good treatment throughout the summer months, the soil will be in excellent condition for seeding the latter part of August or early in September. This plan also facilitates the storage of water within the soil, and the alfalfa plant has a full and continuous supply at hand throughout that period of the year when the rainfall is comparatively light.

Another illustration will serve to make this point somewhat clearer. The station at Stillwater has found that early (July) plowing for wheat gives better returns on the average than late (September) plowing. In this test the ground was plowed on or about July 15, August 15, and September 15 each year, and these plowings were designated "early," "medium," and "late," respectively. Duplicate plats were used in each case. The soil was turned to a depth of 7 to 8 inches and worked down immediately. Subsequently the plats were given light cultivation after each shower or heavy rain. The different areas were all drilled at the same time to Fulcaster wheat at the rate of 1½ bushels per acre. The time of seeding for the five years through which this experiment was carried ranged from September 15 to October 1. The yields are given in Table III.

TABLE III.—*Yields of wheat at Stillwater, Okla., from 1900 to 1904, inclusive, showing the effect of early, medium, and late plowing.*

Year.	Early plowing.		Medium plowing.		Late plowing.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Bush.	*Tons.*	*Bush.*	*Tons.*	*Bush.*	*Tons.*
1900	31.32	1.81	23.48	1.23	15.30	1.00
1901	43.60	1.99	38.20	1.74	40.20	1.92
1902	17.05	.63	18.15	.61	19.35	.81
1903	28.20	1.74	28.50	1.82	27.80	1.73
1904	15.25	.82	12.54	.56	7.51	.34
Average	27.10	1.39	24.20	1.19	22.00	1.15

In five years the early plowed plat produced a total of 135.5 bushels of grain and 6.99 tons of straw per acre; the medium plowing produced 120.7 bushels of grain, with 5.96 tons of straw, and the late plowing produced a total of 110.1 bushels of grain and 5.78 tons of straw. This makes a total difference in five years of 14.8 bushels of grain and 1.03 tons of straw in favor of the early plowing as compared with the medium plowing, and a total difference of 25.4 bushels of grain and 1.21 tons of straw in favor of early plowing as compared with late plowing. These results lead to the conclusions that better yields can be obtained by plowing early in the summer the land which is to be seeded to wheat. This means July 1 to August 15.

The same publication from which these results were copied states:

> It should also be observed that these results were obtained on ground that was given good cultivation after early plowing. Early plowing alone will not suffice. The seed bed must be thoroughly prepared. On a great many farms the plowing is done at an early date, but the fields are allowed to remain in an open, broken condition until a few days before seeding commences, when the surface of the field is given a stroke with the harrow and the grain is drilled immediately. In the interval between the time of plowing and seeding the mechanical condition of the soil has not been improved. The fields become covered with weeds and moisture evaporates rapidly; consequently a poor seed bed and an imperfect germination result.[a]

If we had complete records of the moisture content of these plats during the progress of the experiment we would undoubtedly note an appreciable difference in the percentages shown for the respective treatments, especially during the more unfavorable seasons. If this is true, and we must concede the fact that our experimental data point in this direction, then in planning the rotation for this section some attention should be given to the monthly average precipitation, in order that we may be able to store a full supply of moisture for the growing crop. The different plants in use also consume varying amounts of water; hence, our plan should include a study of the moisture requirements of the crops in question. Our first principle may be resolved into a simple statement which reads thus: (1) The rotation should be so arranged that it will be possible to make the best use of our rainfall; and (2) it should not interfere with the needs of the subsequent crops so far as the moisture is concerned.

We come now to another phase of the subject. The tiller of the soil wishes to maintain the productive capacity of his soil; therefore, the arrangement prescribed must meet the food requirements of the plant if maximum yields are to be maintained. This was the idea which found a prominent position in the minds of those men who were instrumental in giving to the world some well-defined systems. The Norfolk four-course rotation may be mentioned as one of these. Turnips, barley, clover, and wheat were the crops which comprised the list. Coming down to a later date we find that our foremost agricultural investigators have emphasized the importance of maintaining the productive capacity of the soil; hence, they planned their work and made suggestions with this end in view. Permit me to offer another quotation from Sir Henry Gilbert:

> Although different and sometimes very large amounts of these typical mineral constituents are taken up by the various crops constituting the rotation, there is no material export of any in the salable products except of phosphoric acid and potash; and so far, at least, as phosphoric acid is concerned, experience has shown that it may be advantageously supplied in purchased manures.

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[a] Bul. 65, Oklahoma Agricultural Experiment Station, "Wheat Growing."

But although the eventual loss to the land of mineral constituents is in a self-supporting rotation comparatively so small, the very fact that the different crops require for their growth not only very different amounts of individual constituents, but require these to be available within the soil in very different conditions, both of combination and of distribution, points to the conclusion that in any explanation of the benefits of an alternation of crops the position and the rôle of the mineral constituents must not be overlooked, and the less it can be when their connection with the very important element the nitrogen of the crops is considered.

Some agricultural writers of the past have insisted that a well-planned rotation aids in maintaining the fertility of the soil, but they have failed to include the statement that some return in the way of farm manure must be made if large crop yields are to be secured. Perhaps it would not be out of place to make a brief inquiry concerning the removal and ultimate distribution of the essential constituents of plant growth. It has been intimated that a rotation of crops offers a more satisfactory plan for the return of farm manure to the various fields, but the question of making a complete return was not discussed. This leads us to a study of the percentage of the elements which are found in a sample of average manure, and we shall also consider the amount of the mineral constituents which are taken from the soil by our staple crops.

Farm manure is made up of the liquid and solid excrements of the farm stock, together with the litter which has been employed. The term farm manure was formerly used to include all substances which were applied to the land for the purpose of enriching it. "Latterly the meaning of the word has changed somewhat, and it does not now embrace commercial fertilizers or those substances whose chief object is to improve the physical condition of the soil." Farm manure is sometimes called a "general manure," because it contains all the constituents of plant growth and it is likely to be generally useful in all soils. A knowledge of the composition of farm manure is essential to a proper understanding of the principles which have bearing not only upon the preservation of the material, but also in the application of the manure to the land. The composition of manure obtained from different sources varies in a great many cases to quite an extent, but in spite of this fact uniform results have been secured in many laboratories, and a few statements made will be based upon these results.

"Having regard to the more trustworthy of the analyses given in the tables, it will be seen that 100 pounds of good farm manure contains from 70 to 80-odd pounds of water, or say three-quarters of the weight of the whole manure, and it is safe to allow for each 100 pounds of the manure as much as four-tenths to six-tenths of a pound of potash, five-tenths to nine-tenths of a pound of lime, and about two-tenths of a pound of magnesia." In simple form the percentage of the essential elements present in the manure may be stated as follows: Nitrogen, .49 to .69 per cent; phosphorus, .06 to .15 per cent; and potassium, .33 to .49 per cent. If 10 tons of manure are applied to an acre of land once in three years, then 120 pounds of nitrogen, 30 pounds of phosphorus, and 98 pounds of potassium would be added to the soil. A three-year rotation of corn, wheat, and clover, where the crops approximate 100 bushels of grain for the corn, 40 bushels of grain for the wheat, and 3 tons of hay for the clover, removes 266 pounds of nitrogen, 38 pounds of phosphorus, and 120 pounds of potassium. According to this calculation, more plant food will be taken from the field in the grain and hay than is returned in the 10-ton application of average manure. The wheat, straw, and corn stover were not taken into account in this table. These figures serve to show, however, that although manure contains all the fertilizing elements, the quantity returned to the soil under average conditions is not sufficient to equal the amount which has been removed by the crops in question.

Farm manure has given good results when applied to Oklahoma soils, even in cases where continuous cropping is practiced, and we believe that still better returns can be secured in the application of this material to fields which are placed under a systematic course of cropping. In 1893 an acre of virgin soil was laid out for a continuous culture experiment with wheat. This plat was cropped to wheat annually, without the addition of manure or fertilizers of any kind, up to the summer of 1898, at which time the acre was divided into two sections of one-half acre each. One of these received an application of barnyard manure at the rate of 15 tons per acre in the fall of 1898 and another application at the rate of 11 tons per acre in the fall of 1899. This area received no further application of manure until the summer of 1904, at which time the plat was given a dressing of average, well-rotted, farmyard manure at the rate of 18 tons per acre. The manure, which was applied in July, was very moist, and it was therefore necessary to make a heavier application than would have been the case if the manure had been in ordinary condition. The remaining half of the original plat has received no manure or fertilizer whatever, but has been cropped continuously to wheat since the experiment started. Both plats have received the same cultural treatment, as follows: The plowing was invariably done in July, to a depth of 6 to 7 inches, and the soil was kept in a good state of tilth up to seeding time. The yields for an eight-year period are shown in Table IV.

TABLE IV.—*Yields of wheat on manured and unmanured plats in Oklahoma, 1899 to 1905, inclusive.*

Year.	Manured area.		Unmanured area.	
	Grain.	Straw.	Grain.	Straw.
	Bush.	*Tons.*	*Bush.*	*Tons.*
1899	30.60	2.76	12.00	1.31
1900	36.80	2.50	18.10	1.16
1901	37.70	1.43	28.00	....
1902	17.40	1.08	15.30	.74
1903	27.60	2.16	20.30	1.39
1904	15.70	.73	12.60	.57
1905	11.18	1.53	4.75	.55
1906	23.26	2.00	7.10	.72
Average	25.09	1.77	14.76	.99

In this field trial an average increase of 10.33 bushels per acre per annum was obtained by giving the treatment indicated. It is interesting to note that the average yield for the unmanured ground slightly exceeds the average yield for the Territory, according to the reports issued by the National Department of Agriculture.

If we refer again to our calculation on the losses due to cropping, we reach the conclusion that there is a marked deficiency with respect to the element nitrogen, and as no suggestions were made concerning methods of securing this constituent for the crop, your attention is directed to the following paragraph, which appears in Bulletin 74 of the Oklahoma Agricultural Experiment Station:

> The cowpea and soy bean can not only be used to advantage in securing practical results in the management of farm crops, but the plants also serve a useful purpose from a fertility standpoint. These plants, as well as other members of the legume family, are able, through the medium of microscopic organisms which are found in small tubercles or nodules on the root systems, to assimilate free nitrogen from the soil air. This nitrogen is stored up within the plant in an organic form, and if the crop is used as a green manure the nitrogen in turn is rendered available for plant growth. Nitrogen is designated an essential element, and rightly so, because without this substance the plant or crop can not develop. In fields where the supply of nitrogen becomes deficient through the adoption of improper methods of soil management, the crop under average conditions does not make a normal growth; hence, in order to obtain maximum yields on such lands this element is frequently applied in some commercial form. The crop systems which are in vogue in the Southwest favor nitrogen exhaustion; thus, if the present plans are continued it will be but a short time until our lands will cease to return profitable yields. Nitrogen when purchased in commercial form is an expensive element, and if care and judgment are not exercised in the application of the fertilizer serious losses are likely to accrue. On the other hand, the use of legumes—and we speak more particularly of the cowpea and the soy bean—appears to offer a safe and satisfactory solution for the problem of nitrogen restoration. It should be observed that the necessary bacteria must be present in the soil in order to insure the development of tubercles on the roots. In this section the cowpea nodule-producing bacteria are normally present in

the soil, but the soy bean fails to produce tubercles on its root systems. Where the proper bacteria are wanting they can be supplied by obtaining samples of soil from a field where the germs are present and scattering the same on the uninoculated area.

These crops should be given a conspicuous position in our rotation. Inasmuch as the seasons in this section are comparatively long, the cowpeas and soy beans may be used as catch crops to follow wheat and spring grain. Alfalfa should be grown on the best land, and when a first-class set is obtained it will scarcely be profitable to replow the field for at least six or eight years. This plan throws one section of the farm out of the regular order of cropping, but it may be used in the rotation as soon as a second section is seeded to alfalfa.

There is another phase of this subject which should be considered. It has already been remarked that a given crop, Indian corn, makes a much better record in following a crop like potatoes or soy beans than in cases where it follows sorghum or Kafir corn. In the rotation, therefore, some attention should be given to these discriminations. Minnesota Station Bulletin 50 says: "Rotations were begun in 1894, and thus far potatoes followed by mangolds, corn, or field peas, wheat, and flax in the order given best prepared the land for the succeeding crop."

The Rhode Island Station Report for 1897 contains the following statements:

> The average results for two seasons indicate that when potatoes are planted on a clover sod a better yield is obtained than when the crop is planted after corn. The growth of potatoes upon the clover sod plats was very rapid and vigorous, indicating the presence in the soil of considerable available nitrogen. Clover and lupines gave better results when grown after some other leguminous crops than when grown on a soil which had not produced a crop of that class for several years.

There is another item which may have a very important bearing in the arrangement of plans for the southern farmer. It is comprehended in the following statement in Louisiana Agricultural Experiment Station Bulletin 16, 2d series:

> Several years ago the following rotation was decided upon as the best combination attainable in this section. This rotation is corn, oats followed by cowpeas, and cotton. This rotation is faulty in principle but correct in practice and was adopted last season after two years' trial. The corn should precede cotton, but experience has demonstrated that Red Rustproof oats, the only variety successfully grown here, must be planted in October if maximum results are desired. Cotton can not be removed in time for the crop, while corn can.

The rotation may be arranged in courses of any number of successive crops; thus, the farm can be divided into three, four, or five sections, and the form or plan best suited to the particular branch of agriculture in which we are engaged may be adopted.

The following is a good three-year rotation for northeastern Oklahoma: (1) Corn; (2) oats; (3) wheat followed by cowpeas. For the southeastern section of the State the three-year rotation may be as follows: (1) Corn; (2) oats followed by cowpeas; (3) cotton.

These rotations are arranged to meet the requirements of farmers. Farm manure can be applied to the respective fields prior to cropping the area with corn. If a spring variety of oats is used in each case, a catch crop of cowpeas might follow corn, although one could expect a reduction in the yield of corn by following such a method. The cowpea seed can be sown when the corn is "laid by." It will be seen that a winter variety of oats may be used to follow corn; hence, if better results can be secured by using such a variety than in the case of spring varieties, there will be sufficient time to prepare the land and sow the seed after removing the corn. This applies more particularly to southern sections of the State. In the cotton-growing sections a four-course rotation could be arranged by using the three crops included in No. 1. The cotton in this case would follow wheat, and the cowpea crop might be used to advantage for green manure to be turned under after the wheat is harvested.

The following is suggested as a suitable five-year rotation for farmers in central Oklahoma: (1) Corn; (2) kafir; (3) cotton; (4) oats; (5) wheat followed by soy beans. For northwestern Oklahoma the following is suggested: (1) Broom corn; (2) a legume crop; (3) wheat; (4) brome-grass; (5) brome-grass.

It may be stated in connection with the last of these five-year rotations that a legume like cowpeas can hardly precede wheat, provided the seed of the latter crop is sown in the autumn; but, if spring wheat (durum) is grown, such a plan will give satisfactory results. With winter wheat this combination would tend to exhaust the soil moisture and reduce the yield of wheat quite perceptibly. We are not in a position to state definitely whether brome-grass will thrive in the northwestern section, but, as it has given good results in Kansas and Nebraska, we have included the same in the five-year rotation suggested for northwestern counties. In the central and southern parts of the State brome-grass has never given very satisfactory results; consequently, this grass has not been recommended for those sections. Bermuda grass makes an excellent substitute, but it can not be manipulated as well in the rotation on account of its habits of growth. This grass is propagated mainly by scattering the roots in small furrows and covering them with a shallow layer of earth. Such a method requires considerable labor; hence, when a given area has been set to grass it is generally advisable to allow the same to remain down for a period of years. Alfalfa is also allowed to stand for a period of six or eight years. Farm manure can be applied to the land in both of the five-year rotations suggested immediately preceding corn, or it may be incorporated with the soil early in the summer preceding wheat.

The following is suggested as a six-year course: (1) Corn; (2) oats followed by cowpeas; (3) kafir or sorghum; (4) cotton; (5) cowpeas (harvested); (6) wheat followed by soy beans. A five-year course of cropping followed by five years in alfalfa is suggested in the following: (1) Corn; (2) oats followed by cowpeas; (3) kafir or sorghum; (4) cowpeas or soy beans; (5) wheat; (6) alfalfa for five years.

These rotations are somewhat more extensive than the preceding. In both cases legumes are grown on three fields during a given season, and one could plan to use two of these crops for green manure provided the soil is deficient in humus. The stockman-farmer can use such crops to good advantage for feeding purposes, and then return the manure to the land. In the case of the last rotation given, the farm is divided into six fields, and five of these are subjected to an alternation of crops annually. At the end of the fifth year the alfalfa crop is moved to a new section, and the old alfalfa field is used in the yearly series. This plan presupposes that the entire farm is suitable for alfalfa. In planning a rotation the following facts should be taken into account:

(1) The rotation should be arranged to make the very best use of the annual rainfall.

(2) The productive capacity of the soil should be maintained; thus our crop system should be comprehensive enough to include provisions for the realization of this object.

(3) Various crops differ in their moisture capacities; consequently the rotation should be so arranged that one crop will not suffer because the preceding crop consumes an abnormal amount of moisture.

(4) It has also been stated that a given crop may do much better when preceded by a crop of potatoes than in cases where the land was previously devoted to a cereal. The likes and dislikes of the plant should be considered.

DRY-LAND PLANT BREEDING.

By J. H. SHEPPERD, *Director, North Dakota Agricultural Experiment Station, Fargo, N. Dak.*

The possibilities in dry-land plant breeding are so great that I feel that it will be a mistake not to enlist the side time of each scientific worker who comes in contact with plant life in the region.

Mendel, the Austrian monk, found time from his devotions to breed peas, and incidentally evolved one of the strongest hypotheses that the breeding world has ever received. Hugo De Vries, a Dutch botanist, found time to work upon scientific features of breeding and even to evolve a theory which has set the scientific world agog as to whether he has not more truly solved the question of the origin of species than did Charles Darwin.

The originators of the Concord grape and of the Wealthy apple are alike men who simply caught them up as side issues.

Light horses, poultry, dogs, pet stock, and flowers furnish more evidence of good sensible breeding than do any other classes of living domestic things, and they are simply the result, in a large part, of the side efforts of wealthy people.

You young men represent the only organized body of persons who are interested, in a broad and permanent sense, in the upbuilding of the dry-land region of the West. You are trained scientific men and you are brought in contact with large numbers of plants of the best-adapted sorts which the world can supply, and this enlarges your chance of happening upon the mutant of De Vries, the Concord grape, or the Justin Morgan of the light-horse world.

The climate makes you a strong and unbiased ally in selecting the Darwinian survival of the fittest for the Great Plains region.

Animal breeders hold that the success of Robert Bakewell and the many successful breeders of later generations in old England was due to the fact that live stock was bred so much by geographical districts, more commonly by counties, that the observing breeder by short horseback journeys could see hundreds to thousands of head of the particular breed and class in which he was interested and consequently could select the superior individuals, the result being that the world's breeds of domestic live stock, exclusive of swine, nearly all trace to the " tight little island." Do you not have a similar opportunity, with interested neighbors who are anxious to grow stock of all the new things which you can recommend, who are glad to have you inspect their fields for prime specimens and who will, indeed, aid you in the task?

I am convinced that the Great Plains area has possibilities for producing crops of high quality which the balance of the country can not duplicate. It is a region noted for the clear air and intense sunlight. The fact that it is a dry-land country means more hours of sunshine than other portions of the country have, which, together with dry air, makes almost ideal natural disinfecting conditions. Absence of disease is certainly a great aid to the production of high quality. Dry ripening and curing weather are great aids in the production of high quality of crops, and I shall be surprised if the day does not come when the dry-land region will be looked to as the source of high quality in crop products.

Durum wheat, nonsaccharine sorghum, and several of the horticultural plants are sufficient indication that there are special types of plants particularly adapted to the dry-land region. The successful culture of slender wheat-grass (*Agropyrum tenerum*), Burbank's spineless cactus, and Hansen's native fruits indicates that foundation and acclimated stocks may be at your very doors if you will but guide nature's acclimated products into cultivated-plant channels. You are really engaged in a battle of conquest. You are at work upon a plan calculated to add territory to the profitable farming country. You are doing much by methods of moisture conservation and have much in prospect from that line and from the study of a sensible method of cropping, and it seems to me that it will be a fatal mistake not to take in this third ally—plant breeding—if not on an extended scale, certainly as a side line.

To those who go into plant breeding I would suggest two things: First, do not undertake too extensive a line of work; second, make sure to keep a plain, easily traceable record.

Interest in too many lines of breeding work will scatter your energies too much and force neglect. It is hard to throw away breeding stock, and especially when you have not worked it over thoroughly, as there is always the fear that you are throwing away the one which should be kept.

Keeping a record of plant-breeding stocks soon becomes a serious matter, as they rapidly run into large numbers and many generations. A plan of record keeping which would answer the needs, at least of those who practice plant breeding as a side line, is to indicate series by the letters of the alphabet and generations by figures.

One of the great needs of the dry-land region is the breeding of legumes, particularly clover and alfalfa; also the development of suitable grasses. In that work special provision will need to be made to prevent your climate ally in selection from destroying your entire stock. Nature's selection is spasmodic, and during some seasons it is so severe as to eliminate good and bad alike. It is always wise to make provision for the future by saving a portion of your seed supply for a start during a second season. With the legumes and grasses at least two seasons' failure should be guarded against, for in addition to winterkilling there is the chance of a failure to secure a "catch" of plants which will be able to live through the trying times of the growing season.

I am convinced that there is great opportunity for improvement in the forage crops for the dry-land district, and particularly among the nonsaccharine sorghums, which can be selected and handled in much the same manner as corn breeding is done. Since they are annuals the chance of losing your entire improved stock of seed is much less than it would be with a biennial or perennial plant. They have individuality like corn, and hence are more easily handled in the nursery and in the pedigree record.

In closing let me urge that those employed at stations where the breeding work is not undertaken by a special man be upon the alert for the strong-constitutioned, vigorous, heavy-yielding, thrifty plant whose descendants are liable to be especially valuable. Those who come in contact with plants in large numbers have the chance to discover the Shakespeare of the species, and if De Vries's mutation theory is right it may be that a ready-made constant producer of a similar sort will be sighted. In any event it will prove an interesting line of study for the young man who gives it attention.

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